PHILOSOPHICAL

TRANSACTIONS,

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCXX.

PART II.

LONDON,

PRINTED BY W. BULMER AND W. NICOL, CLEVELAND ROW, ST. JAMES'S;
AND SOLD BY G. AND W. NICOL, PALL-MALL, BOOKSELLERS TO HIS MAJESTY,
AND PRINTERS TO THE ROYAL SOCIETY.

MDCCCXX.

CONTENTS.

VIII. *On a new principle of constructing ships in the mercantile navy.* By *Sir* ROBERT SEPPINGS, *F. R. S.* p. 133

IX. *On the milk tusks, and organ of hearing of the Dugong.* By *Sir* EVERARD HOME, *Bart. V. P. R. S.* 144

X. *Upon the different qualities of the alburnum of spring and winter-felled oak trees.* By THOMAS ANDREW KNIGHT, *Esq. F. R. S.* 156

XI. *On the mode of formation of the canal for containing the spinal marrow, and on the form of the fins (if they deserve that name) of the Proteosaurus.* By *Sir* EVERARD HOME, *Bart. V. P. R. S.* 159

XII. *Some experiments on the fungi which constitute the colouring matter of the red snow discovered in Baffin's Bay.* By FRANCIS BAUER, *Esq. F. L. S. In a Letter addressed to the Right Honourable Sir* JOSEPH BANKS, *Bart. G. C. B. P. R. S.* 165

XIII. *Some account of the Dugong.* By *Sir* THOMAS STAMFORD RAFFLES, *Governor of Sumatra; communicated in a Letter to Sir* EVERARD HOME, *Bart. V. P. R. S.* 174

XIV. *Observations on the Human Urethra, showing its internal structure, as it appeared in the Microscope of* F. BAUER, *Esq.* By *Sir* EVERARD HOME, *Bart. V. P. R. S.* 183

XV. *On the Errors in Longitude as determined by Chronometers at Sea, arising from the action of the iron in the ships upon the Chronometers.* By GEORGE FISHER, *Esq. Communicated by* JOHN BARROW, *Esq. F. R. S.* 196

XVI. *An account of a new mode of performing the High Operation for the Stone. By Sir* EVERARD HOME, *Bart. V. P. R. S.* p. 209

XVII. *A Sketch of an Analysis and Notation applicable to the estimation of the value of Life Contingencies. By* BENJAMIN GOMPERTZ, *Esq. F. R. S.* 214

XVIII. *On the measurement of Snowdon, by the Thermometrical Barometer. By the Rev.* F. J. H. WOLLASTON, *B.D. F.R.S.* 295

XIX. *On Sounds inaudible by certain ears. By* WILLIAM HYDE WOLLASTON, *M. D. P. R. S.* 306

XX. *Particulars respecting the anatomy of the Dugong, intended as a Supplement to Sir* T. S. RAFFLES' *Account of that animal. By Sir* EVERARD HOME, *Bart. F. R. S.* 315

XXI. *On the compressibility of Water. By* JACOB PERKINS, *Esq. Communicated by the late Right Hon. Sir* JOSEPH BANKS, *Bart. G. C. B. P. R. S.* 324

XXII. *Astronomical Observations. By* STEPHEN GROOMBRIDGE, *Esq. F. R. S.* 380

Presents received by the Royal Society, *from November*, 1819, *to July*, 1820. 388

Index. 345

PHILOSOPHICAL TRANSACTIONS.

VIII. *On a new principle of constructing ships in the mercantile navy.* *By Sir* ROBERT SEPPINGS, *F. R. S.*

Read March 9th, 1820.

So deeply is this country in particular interested in whatever may tend to give additional safety to the number of persons, and the immense sums of money employed in commerce, that I trust I shall stand excused for again bringing to the notice of the Royal Society, the subject of the construction of ships. The description of vessels of which I am now about to treat, are those employed in our mercantile service, in the construction of which, the imperfections are such as on a close examination will, I conceive, leave but little doubt that lives and property to an immense amount, must, from time to time, have been sacrificed by the present injudicious mode of constructing these ships; and under that impression I have presumed to lay this paper before the Society.

And first, as to the principle on which mercantile ships are at present built, and particularly as regards the putting

together their ribs or frames, and the arrangement of the materials.

In forming the frames or ribs, half of the timbers only are united so as to constitute any part of an arch; every alternate couple only being connected together: the intermediate two timbers (termed fillings) being unconnected with each other, and merely resting upon the outer planking, instead of giving support to it. Now, it must be very evident that ships so constructed, can by no means possess equal strength with those that have the whole of their timbers formed into frames or arches.

This loose practice is, I believe, peculiar to the English merchant ship-builder; and indeed was pursued till very lately even in His Majesty's Navy, while the preferable system of connecting the ribs was common to other maritime powers.

The principle of uniting the frames, lately introduced in the construction of English ships of war, might, no doubt, be also introduced into the mercantile navy; which would give to the ships in that employ additional strength and increased durability, without adding to the expense of building.

But the present mode of joining together the several pieces of the same rib, is also highly objectionable. It is done by the introduction of a third piece, technically termed a *chock* or *wedge piece*, (Pl. VIII. Fig. 1, marked A) of which pieces the number amounts to upwards of 450 in a 74 gun ship, and not less than that number in an Indiaman of 1200 tons: (to which class of ships the drawings in this statement have reference.) Of these chocks not one in a hundred is ever replaced in the general repair of a ship; for they are not only

found defective, but very generally to have communicated their own decay to the timbers to which they are attached. Besides this, the grain of the rib-pieces being much cut, to give them the curvature required, has a considerable share in weakening the general fabric. That they occasion a great consumption of materials, is obvious, as the ends of the two rib-pieces must first be cut away, and then be replaced by the chock.

This mode of putting together the frame, is also peculiar to the English ship-builder; and I find, from an old work in my possession, dedicated to GEORGE the First, that the practice was introduced in the construction of English ships about the year 1714; and having heard that so unfriendly to it was the builder (Mr. NAISH) of the Royal William, that he refused to adopt it; and being desirous of ascertaining the fact, when that ship was taken to pieces at Portsmouth, in 1813, I found that she was built without the wedge pieces or chocks, to which, in a certain degree, I ascribe her strength and durability; her ribs being by her structure less grain-cut, and for want of chocks, less liable to decay in those parts where they are inserted.

The introduction of chocks, was no doubt to procure that curvature which is so necessary in the formation of a ship, when crooked or compass timber became scarce; as may be seen by Pl. VIII. Fig. 2. which describes the shape of a piece of timber in the converted form; and by which it will also be seen, that the introduction of the chocks assists in obtaining the required curve. But this curve may equally be obtained by a different combination of materials, and at a considerable less consumption of useful timber.

The frames of a mercantile ship (on the present mode of building) before they are placed and united to each other, may be seen in Pl. VIII. Fig. 3, with their chocks or wedge-pieces. To the evils already stated of the present practice, may be added that of imperfect workmanship, so that the surfaces of the chocks are seldom in contact with those of the timbers; and the ends of both are frequently reduced so thin, as to split by the fastenings that are necessary to secure the planks to the ribs; and thus the ship, in the event of grounding, or even in the act of rolling, derives little support from timbers united only, in fact, by two narrow edges.

Another great defect arising out of the present plan of constructing mercantile ships is, that the ends of the lower ribs or timbers, commonly termed the lower futtocks, (Pl. VIII. Fig. 3. B) are not continued across the keel C, so that no support is given in a transverse direction when the ship touches the ground; nor any aid to counteract the constant pressure of the mast. This great sacrifice of *strength* and *safety* is made for no other purpose than that of giving a passage for the water to the pumps.

The floor timbers, which by this mode of construction are the only timbers that cross the keel, are also weakened for the same purpose, as shown at D, Pl. VIII. Fig. 3. This mode also makes the conveyance of the water very uncertain, for the passage is not unfrequently choaked; and the pumps (from its not being practicable to continue them sufficiently down) always leave from 6 to 8 inches of water in the ship; so that these compartments constantly contain a certain quantity of putrid bilge water, offensive and injurious to the health of those on board.

The deficiency of strength causes also an alarming insecurity in the plank of the bottom, as shown at E, Pl. VIII. Fig. 3. termed the garboard strake; which consequently, has no other fastening to the general fabric, than its connection with the keel at F, Pl. VIII. Fig. 3. and a slight security at G, Pl. VIII. Fig. 3: hence it is obvious, that in the event of the keel being disturbed, the garboard strake, from its being attached to it, must share the same fate as the keel, and in that case the loss of the vessel would be inevitable.

To obviate these serious defects, is the principal object of this paper.

The principle I would recommend is explained in Pl. IX. Fig. 4; by which it will be seen, that the component parts of each rib are of shorter lengths and less curvature, and consequently less grain-cut; that they are more firm and solid by the substitution of coaks or dowels, for chocks or wedge-pieces; and that the mode of connecting the lower timbers is better adapted, in the event of a ship grounding, to give support and strength to the fabric, as will appear by the line marked H.

The plan of connecting the ends of the timbers by circular dowels or coaks (as at I,) is simply that which has, from time immemorial, been practiced to unite the fellies of carriage wheels; and we learn from Mr. Wood, that the same method has been observed in joining together the separate pieces of the shafts of the stone columns in the ruins of Balbec. "Little more of this great edifice (says this author) "remains, than nine lofty columns supporting their entabla-"ture. It is remarkable, that the shaft of these columns "consists of three pieces most exactly joined together with-

" out cement, which is used in no part of the buildings, they " being strengthened *with iron pins received into a socket.* " How much this method contributed to the strength of the " building, is remarkably seen in the most entire temple, " where a column has fallen against the wall of the cell with " such violence, as to beat in the stone it fell against, and " break part of the shaft, *while the joinings of the same shaft " have not been in the least opened by the shock.*"

That the frame of the Thunderer, (now Talavera) built on this principle, is superior in point of strength, to a frame constructed on the common system, is fully established by a report from the officers of His Majesty's Yard at Woolwich to the Navy Board, who directed them to compare the strength of the frames so united, with those of the Black Prince, constructed in the usual way with chocks or wedges.

It may be necessary to observe, that the frame of the Thunderer is composed of small timber, hitherto considered applicable only for the frames of frigates. I was prompted to attempt the introduction of the plan on which she is built, from there being a surplus store of small timber in the yard, and from a conviction, that a well combined number of small timbers, might be made equal, if not superior, both in strength and economy, to the large, overgrown, and frequently grain-cut materials, made use of in constructing the frames of large ships; and the result has shown the correctness of the principle; the adoption of which cannot fail to prove of great national advantage, in the application of sloop timber to the building of frigates, and of frigate timber to ships of the line, whenever larger timber cannot be procured. On this principle also, may frigates and small ships of war, or merchant

vessels, be built of straight fir, without the assistance of oak or elm, which were formerly employed to give the necessary curvature of the sides. As it respects the general safety of the ship, it will be seen, by Fig. 5 and 6, Pl. IX. X, that the timbers uniformly cross the keel; that the frame of the ship is filled so as to form one compact body to the height marked K; and that only certain internal strakes of plank, or thick-stuff, as it is termed, are introduced, which are those on the joints of the timbers, for the purpose of giving strength where every alternate timber necessarily joins, as shown at L (Pl. X.) All the rest of the inner planking may be omitted; and dunnage battens, brought in a perpendicular direction, upon the timbers *between* the plank, as shown at M, forming regular spaces between each, as is usual at present *upon* the plank; thereby giving an increase of stowage in proportion to the thickness of the plank omitted. Water courses, as shown by dotted lines at N, are to be left in the joints of the timber under the plank, for the purpose of conveying the water to the pumps; which, by this plan, will reach below the water, instead of being some inches above, as is the case with the present mode, before described; consequently, by the proposed system, no stagnant water will remain; and farther, the limber passage, or water course, will be one smooth, uniform channel, which can be cleared with ease, should it be required, whenever the hold is unstowed; whereas at present it is inaccessible in places, and forms compartments for putrid water, without there being any means of removing it.

It is obvious, that a ship on the principle I have here recommended, may sustain the loss of certain planks of the bottom, and also the keel, (which has frequently been found

to have happened to ships of war on their being taken into dock) and still reach the place of her destination; when the loss of *either*, would be the destruction of a ship built on the present mode. It will be evident also, that a ship constructed as now recommended, possesses greater stowage, and more space for leakage, than by the old plan; by the omission of the useless inner planking, and by laying the kentlage on dunnage, leaving a space for the water, which was formerly occupied by the inner lining. This dunnage in the bilge may be formed with the iron kentlage, and thereby serve as ballast, for which it is well calculated from its situation; and by its occupying a space heretofore forming part of the fabric of the ship, will give an increase of stowage, as before stated.

The best mode of closing the openings between the timbers, is by filling the intermediate spaces with pieces of wood, about three inches in depth, of such lengths as the inferior conversions will supply, abundance of which may be procured from the offal. These fillings are to be well caulked, after which the exterior plank is to be brought on. When the works are going on within board, similar pieces are to be fitted internally, and afterwards taken out for the purpose of filling the spaces between the pieces so fitted, with a mixture of PARKER's Roman cement and drift sand, in the following proportions, viz.

PARKER's Roman cement, $\frac{2}{3}$

Drift sand, - - - - $\frac{1}{3}$

previously paying the opening well with coal tar. Where there is sufficient space, a brick, or part of one, may be introduced, provided there is room for cement between it and

the timbers. When filled in to within about two inches of the surface of the frame, the pieces of three inches already fitted and taken out, are to be well driven in and caulked, and by so doing, no space will be left unoccupied. If considered desirable, these pieces may be driven below the surface of the timber, thereby leaving water courses to convey the leakage to the pumps in channels. And prior to launching or undocking of ships, built on the principle I have recommended, it has been the practice to inject the part filled in with mineral tar, by means of a simple forcing pump, boring holes in the joints of the timbers for the introduction of the pipe. By following this method, the air will be excluded, which, as experience has shown, tends much to the durability of the fabric; confirming the assertions made by Doctor HALES on this subject, in his work on Ventilators, published in 1750, and also of Doctor HENRY, in his work on the Elements of Chemistry. If what is here recommended be attended to, and mercantile ships were built under roofs, as ships of war now are, durability would be obtained in addition to safety, from the mode of their construction.

The beams are to be attached to the sides, as shown at O, Pl. IX. Fig. 5. rendering wood knees unnecessary, and requiring only a small number of those of iron.

Pl. XI, marked P, describes the old principle of framing the stern with transoms. Q, the new principle, with timbers similar to the bow, omitting the transoms below the wing or upper transom; and by introducing the new principle on which the floors are made, the necessity of using valuable compass, or crooked timber, hitherto required, and with

difficulty procured for these purposes, is avoided. Uniform support will thus be given, and also an increase of room for stowage.

In large mercantile ships above 500 tons, I would recommend that plate-iron be laid diagonally, as shown in Pl. X.

The principle now recommended will cause a decrease in the consumption of materials, and the difficulty of procuring the necessary curvature will be obviated. It also affords protection from worms externally, and vermin internally. Leaks may be more easily discovered and stopped than by the old method; and in point of additional strength, there can be no doubt. But were farther proof required, I need only state, that the Malabar, of 74 guns, built at Bombay, arrived at Portsmouth in October last, loaded to her upper deck with timber, and during her passage encountered four heavy gales of wind, without showing a symptom of weakness, as will appear by the following Extract from the Survey made by the Officers of Plymouth Yard, on that ship, by order of the Lords Commissioners of the Admiralty.

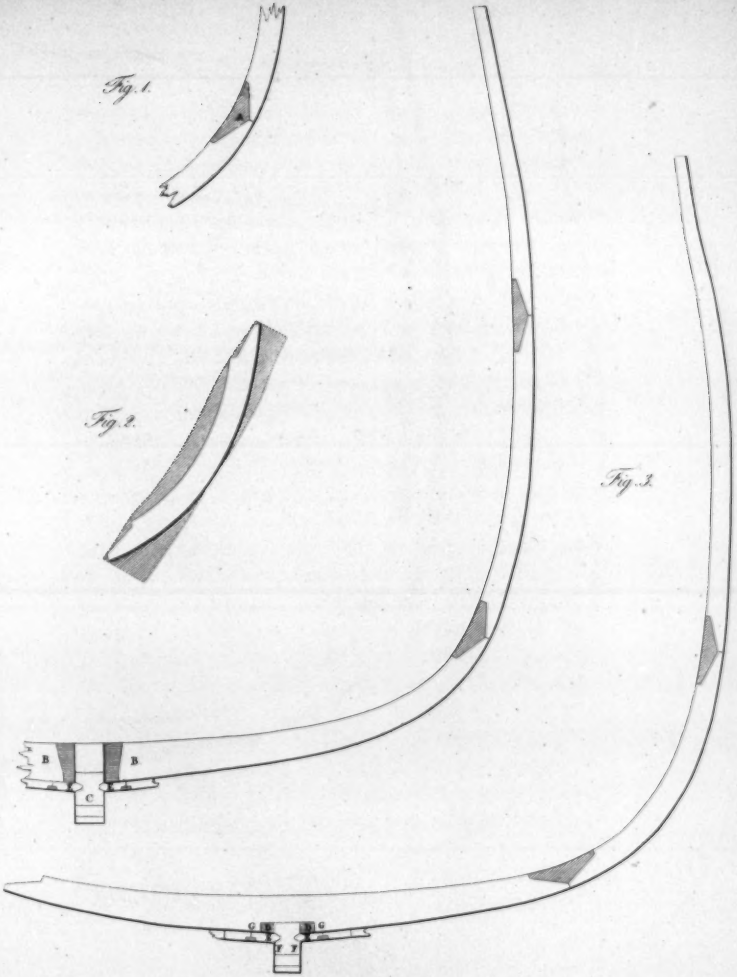
"When we consider the nature of the lading that this "ship has brought home, with the temporary security to "the beams of all the decks, except the orlop, and that on "her passage she encountered four very severe gales of "wind, it must, we presume, be very gratifying to your "Honorable Board to find, that she does not indicate any "past symptoms of weakness or straining in any part."

This ship had no other attachment for her beams than the internal hoops and thick waterway; the remainder of her security, the iron knees, being omitted, (from the difficulty of

Fig. 1.

Fig. 2.

Fig. 3.



J. Basire sc.

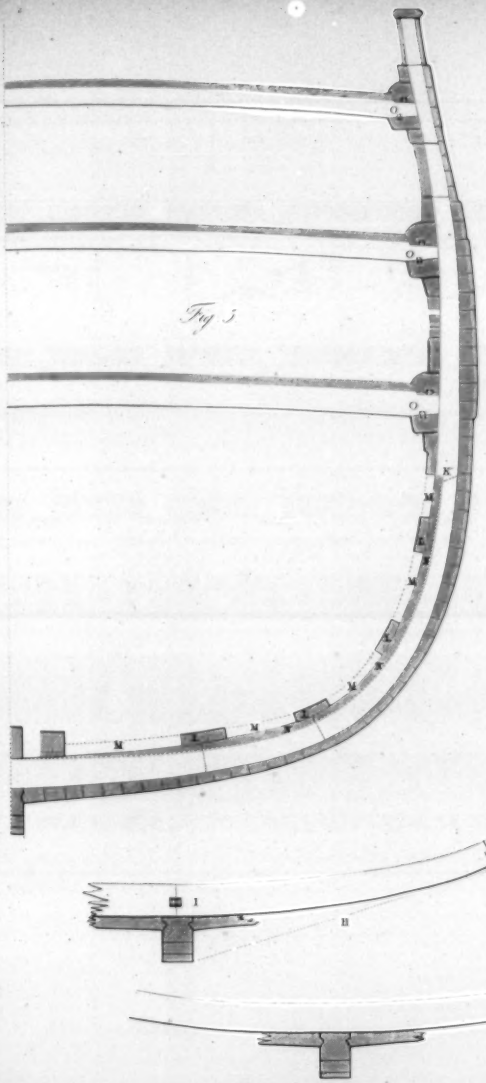
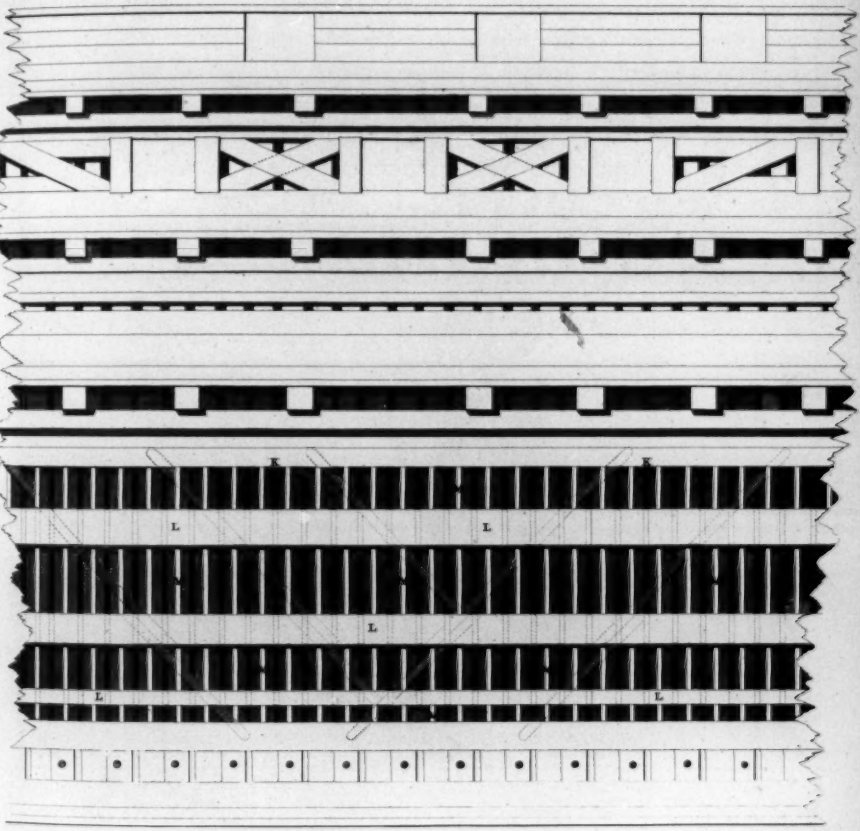
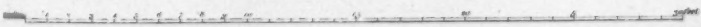
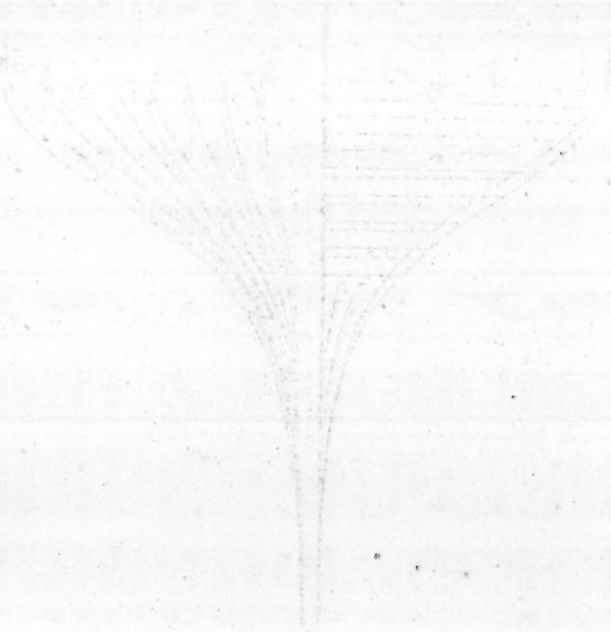
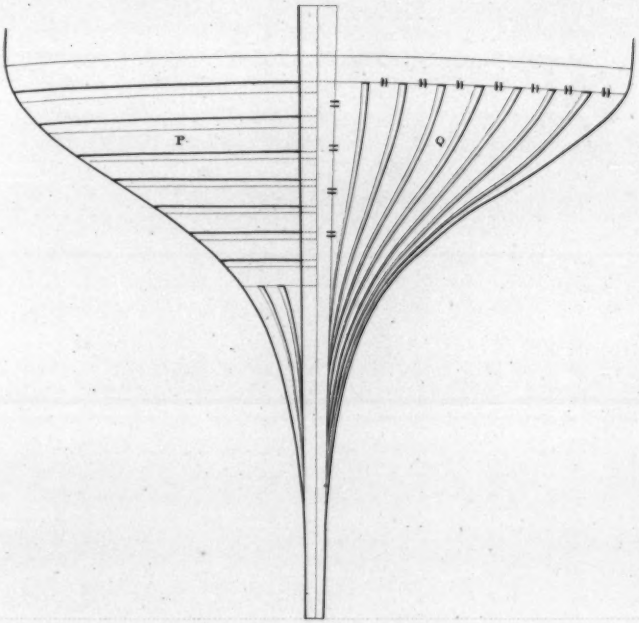


Fig. 3.
O
O
O
K
M
M
M


K
K
L
L
L
L
L


1 inch




P
Q

procuring them in India) until her arrival in this country; thus supporting her cargo without the aid of knees, either of wood or iron.

The advantages of this plain, but important subject, particularly in point of safety, has induced me to bring it before the Society, in the hope that its utility and importance to this great maritime nation, may plead an excuse for the absence of abstract science, to which the attention of the Society may, perhaps, be more peculiarly directed.

IX. *On the milk tusks, and organ of hearing of the Dugong.*

By *Sir* Everard Home, *Bart. V. P. R. S.*

Read April 13th, 1820.

I have found nothing that so much promotes the enquiry respecting those animals with which we are little acquainted, as laying before the public the materials, however scanty they may be, that have been already procured.

By making those materials generally known, naturalists have their minds awakened to the enquiry, and are not only more disposed, but better able to take advantage of such opportunities as come within their reach, to advance our knowledge of that subject.

This at least has happened in so great a degree with respect to the fossil bones of the Proteosaurus, of which very little was known at the time I laid my first observations upon them before the Royal Society, that I am induced to make a similar trial respecting the Dugong, which, I believe, has never been seen of its full size, by any one conversant in comparative anatomy.

On the present, as well as on former occasions, it is not the whole structure of the animal that has attracted my notice, but such parts of it as differed in form from similar parts in other animals most nearly allied to it; as I consider that all peculiarities of this kind are deserving of the notice of this Society, since they bring to our knowledge a new construction of parts, and therefore make us acquainted with animals

that form intermediate links in the chain of gradation between those that are already known. The truth of this observation is very strongly illustrated in the proteosaurus.

Our knowledge of comparative anatomy has been so much encreased in extent within the last few years, that we can now better, than at any former period, attempt the arrangement of animals into a regular order, according to their internal mechanism; showing that they form so many parts of one great system of structures; and if the pursuit is followed with the same ardor, and attended with the like success, we may soon expect to have all the material links of this great chain made out.

To assist our progress towards this end, the great purpose for which comparative anatomy is cultivated as a science, I have in all my researches into the structures of animals, or their fossil remains, kept it in view.

The observations I now bring forward respecting the milk tusks, and organ of hearing of the dugong, have been made upon a skull of that extraordinary animal, in a very perfect state of preservation, sent to me, by my friend Sir THOMAS STAMFORD RAFFLES, from Sumatra.

There are three skulls which I may say have come under my observation, of animals nearly of the same age, but not entirely so, for although the milk tusks at their points in all of them, put on the same appearance, that is not the case with their other extremities. One of these skulls is in the possession of M. CUVIER, and a figure of it is engraved in the thirteenth volume of the *Annales du Museè d'Histoire Naturelle*; and also in the fourth volume of his work, entitled *Recherches sur les Ossimens Fossiles des Quadrupedes*. In this figure the

bones of the ear are not represented; and as in that stage of the animal's growth they have no bony connection with the skull, there is sufficient evidence of their having belonged to a young animal. Another skull is in the collection of comparative anatomy belonging to Mr. BROOKES, in London. In that also the organs of hearing are wanting. The third is in my possession, and is the subject of the present observations; in this the bones of the ear on both sides of the skull are preserved, although they have acquired no bony connection with the skull.

The first examination which it occurred to me to make, was respecting the length of the tusks, the points of which were the only parts exposed. For this purpose, one of the bony canals, composed of the bones of the face in which the tusk is contained, was laid open, and one of the tusks was removed from its socket, and a longitudinal section afterwards made of it. The whole of its substance was found to be solid, showing that it had arrived at its full growth, and was therefore only a milk tusk: at the posterior extremity there was a small shallow cup composed of the same materials, which appeared to be no part of the tusk itself, but, as it were, fixed to the end of it. This was contained in a corresponding cavity adapted to it, in the skull; but upon the upper surface, the bony table of the skull was entirely removed to some extent by absorption, so that the shallow cup at the root of the tusk was exposed externally, giving the skull at that part a very extraordinary appearance. In Mr. BROOKES's specimen, the aperture through the external table of the skull is to a less extent, than in my specimen, but exactly of the same kind. In M. CUVIER's skull, there is no appearance of any breach in

the upper table whatever, so that the process of absorption of the outer table of the skull, to make room for the formation of the permanent tusk, had not begun to take place.

When the section of this tusk was compared with a similar section of the milk tusk of the narwhal, and of the elephant, I found that in its internal structure it closely resembled them; and I noticed that the external surface in all of them was deficient in smoothness, when compared with the permanent tusks of those animals.

In the narwhal, the root of the milk tusk terminates in a rounded blunt end, behind which there is no appearance of any preparation for the formation of the permanent tusk; so that there is no evidence of that tusk having its origin in a cell similar to those of the dugong; but by comparing the place where the root of the milk tusk has its origin, with that of the permanent tusk in the same animal, for the two tusks in the narwhal come forward at such different periods of time, that this comparison may be made even when one permanent tusk appears to have arrived at its full growth, or nearly so; at which time the rudiments of the corresponding permanent tusk have not begun to be formed, and the depth in the skull of the milk and permanent tusk exactly correspond.

As the permanent tusk in the narwhal begins to form in a direct line immediately behind the origin of the milk tusk, the great purpose of the milk tusk is evidently to open the road for, and to direct the course of the permanent tusk, till it is completely pushed out by it. In the elephant, both of whose tusks appear at the same time, and whose skull encreases in size much more rapidly than that of the narwhal, the permanent tusk has its origin even farther forward than

the milk tusk; but then it afterwards has an increase backwards in the space between the tables of the skull, which the tusks of the narwhal have not; and in this growth backwards, which is very slow, corresponding to that of the skull, absorption of the upper table previously formed, is produced, to make room for it. In this way the sockets of the elephant's tusks, which are shallow when the animal is young, acquire an increase of depth as the elephant grows up, to give it sufficient firmness in the skull to support them in the exertions that are made with them.

A similar absorption to what takes place in the upper table of the skull in the elephant, is shown to occur in the dugong; it is however probably at a different period of the animal's growth, as the milk tusk in the elephant is shed between the first and second year, and the absorption of the upper table many years after; but in the dugong, the absorption of the skull takes place just as the milk tusks begin to extend themselves beyond the gums, but the age at which the animal has at this time arrived is not known.

The use of the shallow cup, which appears to be an appendage peculiar to the milk tusk of the dugong, forming no part of the tusk itself, would appear to be for the purpose of receiving the point of the permanent tusk as soon as it is formed; so that as the milk tusk advances in the act of its being shed, the other may be directed forwards in the same course, which is different from that in which it set out.

The facts that were brought forward in a former paper upon the milk tusks of the narwhal, explained many circumstances in the natural history of that animal which were involved in obscurity; and the observations that are now made upon the

tusks of the dugong, show that the milk tusks have been mistaken for the permanent ones, and that the real appearance of the permanent tusks of this animal is at present unknown. Having corrected so great an error in the natural history of this animal, we must wait till we are so fortunate as to procure the skull of a full grown dugong, before we attempt to form any analogies between its tusks and those of other tribes of animals.

The grinding teeth, as will be seen in the annexed plate, are not exactly similar to those of any known animal, but form an approach to the hippopotamus. They consist of two cones united together; but when a transverse section is made, there is no line of separation, the whole being uniform; the external crust is not enamel, nor is it the hardest part; a little within it, there is a narrow rim of a yellow colour, that describes an oval figure, much more dense than the rest of the tooth, although to the eye there is no apparent difference in its texture; all that is within this rim is soft ivory; so that these teeth in wearing down will always have the crown rendered concave.

On the organ of hearing.

In examining the organ of hearing of the dugong, which was done with more facility, as the skull had not been completely formed, I met with a peculiarity, that does not belong, as far as I am aware, to any other tribe of animals. The malleus and incus, which have nearly the same shape as in other animals, are fastened to the sides of the tympanum by a bony substance extending across the intervening space. The malleus is in this way connected to one side of the tympanum,

the incus to the other, so as to render these ossicula in a great measure immoveable. The stapes is unconnected with the foramen ovale, to which it is opposed; nor is it anchylosed with the ramus of the incus. The handle of the malleus projects in the centre of the circle over which the membrana tympani had been spread, so as to leave no doubt that, in the living animal, it is attached to the centre of that membrane.

The nearest approach to this mechanism, is an attachment by bony union of the malleus to one side of the tympanum, which Mr. HUNTER, in his paper on the Anatomy of Whales, states he had met with in some of that tribe; but does not, (which is unfortunate) mention in what species. He says not in the porpoise; and the author knows it is not the case in the balæna mysticetus; so that this structure does not belong to those genera that live principally upon the surface, nor to those that penetrate the unfathomable depths; and as HUNTER describes the organ at length in the pike-whale, without mentioning this peculiarity as part of the description, it could not have occurred in that species. This renders it probable that he met with it in the grampus, or the bottle-nose, and it is very likely in both, as he insinuates that it is not confined to one genus.

The dugong feeds on the plants that grow at the bottom of the sea, and comes in great numbers to the harbours of uninhabited islands, and remains for many hours in the shoal water, where it finds food: at least this account is given of its habits by Mr. LEGUAT, who, with several companions, spent nearly three years in an island previously uninhabited, about fifty leagues from the Mauritius, and the dugong was a

principal part of their food. It is from him we learn that their usual length is twenty feet; but that catching them full grown was a service of danger; nor were they so delicate as food for the table. This gentleman's account was published in 1720, and is written with so much apparent candour, that there is no reason for doubting the veracity of his narrative.

As these habits are allied to those of the hippopotamus, I inquired whether this peculiarity of structure exists in the ear of that animal, but find there is nothing of the kind; all the ossicula are separate, and very readily drop out of the cavity of the tympanum when the skull is deprived of the soft parts. There are peculiarities in the mechanism of this organ in the hippopotamus which deserve being mentioned. The projecting ear and meatus auditorius externus, have a higher situation upon the head than in most other animals; and the tube that passes down to the membrana tympani, is one straight line. The bony portion of it is four inches long, its direction from the external surface of the head down to the membrane, is at an angle of 45°, and its termination is upon a ledge which forms a slight projection beyond the bony ring to which the membrana tympani is attached; the space on the outer surface of the membrane, between it and the opposite side of the tube, is so small, that it cannot exceed the thickness of the membrane itself. The ossicula are small, when the size of the animal is considered; but the cochlea makes two turns and a half, which is by no means common; the semicircular canals have the usual appearance.

This animal I understand, from every enquiry I have been able to make, when it goes down into the water to feed at the

bottom, allows itself to sink by its own weight, descending in a standing posture, so that as soon as the head is covered, the water would pass into the tube of the ears, were there not something like a valve at the orifice of the meatus externus to prevent it. In other animals that live in the sea, or are much under water, there are contrivances, very different from this, to prevent the water getting into the tube of the ear. In the whale tribe, the external orifice is so extremely small, as to exclude it. In the seal, the meatus externus makes a turn nearly circular, to answer the same purpose. In the ornithorhyncus paradoxus, the external opening is at a great distance from the organ; and the meatus, which is the size of a crow quill, and cartilaginous, winds round upon the temporal bone. The external meatus in the walrus, I have not had an opportunity of examining; the orifice in the bony tube corresponds in size with that of the hippopotamus, its termination at the membrana tympani is less oblique, and its direction horizontal. The ossicula in the hippopotamus are small, the stapes is imperforate, and the bones have no bony union.

The external orifice of the meatus externus in the dugong is extremely small, so as readily to exclude the water. The cochlea is very small, making only one turn and nearly one half. The semicircular canals are also exceedingly small. The peculiar bony connections to the tympanum, connecting the malleus and incus with the bones of the skull already described, lead to the idea that this animal is more indebted for its hearing, than any other that lives in water, to the vibrations received by the bones of the skull, being commu-

nicated, through the bony connections that have been mentioned, to the ossicula, and from thence to the cochlea, and semicircular canals.

This animal, although the tail is horizontal, possesses the sense of smell, since there are orifices in the cerebriform plate of the skull for the olfactory nerves.

While this paper was in the press, I have been so fortunate as to receive from Sir THOMAS STAMFORD RAFFLES, another skull belonging to a dugong, 8 feet long, in which the milk tusks had been shed, and the permanent ones had acquired sufficient length to show the degree they project beyond the bony sockets, and the manner in which they are worn down, by rooting up the plants while feeding. They are considerably broader than the milk tusks, even at their points, explaining the use of the cup at the end of the milk tusk being wider than the tusk itself, to admit of the point of the permanent one having this encreased breadth.

These tusks bear a near resemblance to those of the hog, the points being turned a little outwards, and they wear down in the same manner.

It is not a little remarkable, that in writing this paper upon the milk tusks, I should have an opportunity, during an accidental delay in the press, of being furnished with materials to show the appearance of the permanent tusks, which forms so essential a character of the animal, and also to prove that while young, there are incisors in the lower jaw; two of them in the jaw of this skull having been accidentally entangled (while shedding,) in the new bone that was closing

up the socket, and consequently retained there. This is a curious additional fact, and is so far an approach to ruminating animals, whose incisors are only in the lower jaw. These incisors enable the young dugong to crop the tender plants, but are no longer wanted when the animal grows up.

EXPLANATION OF THE PLATES.

PLATE XII.

This plate consists of three figures.

Fig. 1. A side view of the first skull of the dugong, sent by Sir T. S. RAFFLES, in which the organ of hearing is in its place, and one of the tusks exposed through its whole length.

Fig. 2. The longitudinal section of the tusk.

These two figures are in the proportion of half an inch to one inch.

Fig. 3. An exact copy taken from Mr. CUVIER's representation of the dugong's skull, the proportions of which are not mentioned.

PLATE XIII.

This plate consists of three figures, in the proportion of half an inch to one inch. The first represents the basis of the skull of the dugong with milk tusks; the second, the appearance of the permanent tusks in situ; the third, the section of the permanent tusk.

PLATE XIV.

This plate consists of four figures.

Fig. 1. The lower jaw of the skull represented in Pl. XIII.

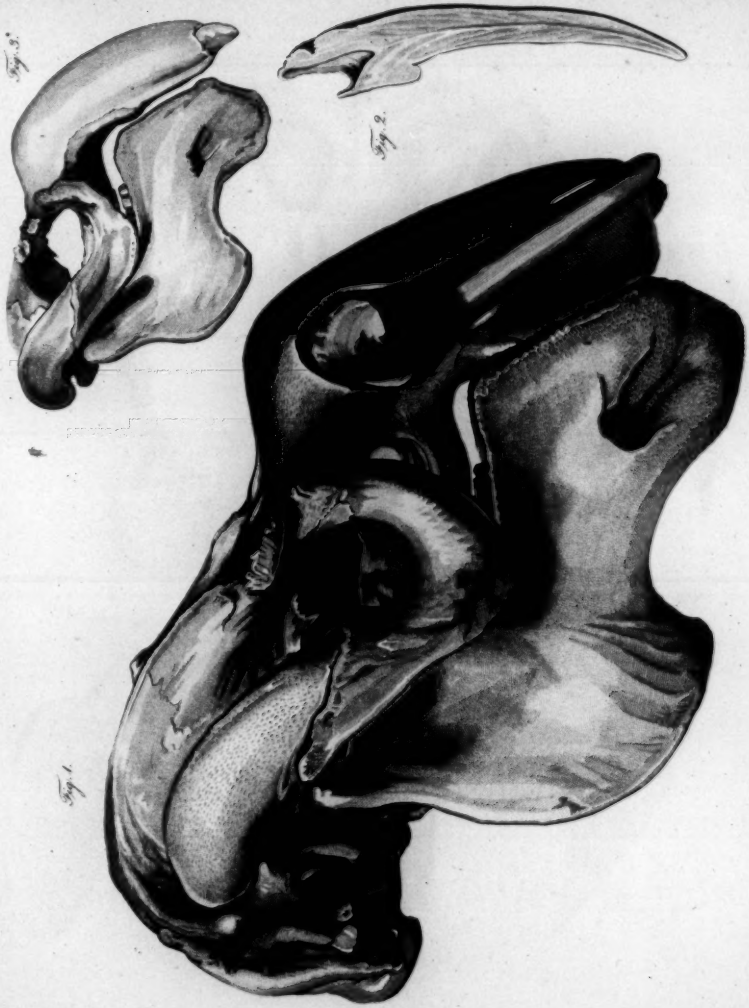


Fig. 3.
Fig. 2.
Fig. 1.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4

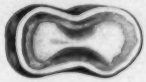


Fig. 1.

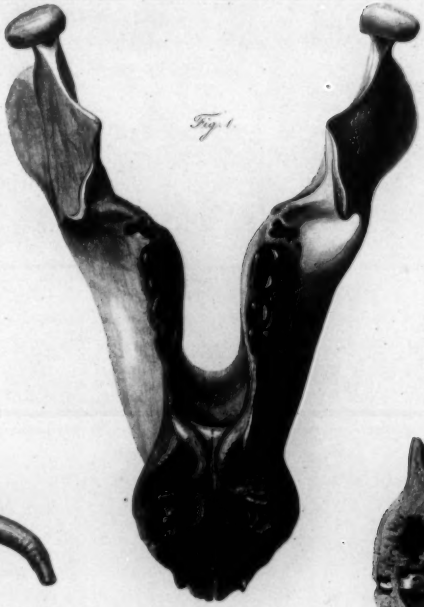


Fig. 3.

Fig. 2.

Fig. 2. The remains of two incisors in situ; both these figures are in the same proportion.

Fig. 3. The two incisors in a shedding state, removed from the jaw, of the natural size.

Fig. 4. A transverse section of one of the dentes molares, represented also of the natural size.

X. *Upon the different qualities of the alburnum of spring and winter-felled oak trees.* *By* THOMAS ANDREW KNIGHT, *Esq. F. R. S.*

Read April 20, 1820.

THE timber of oak trees, felled in winter, was formerly very generally believed to be much superior in quality to that afforded by similar trees felled in spring; and the same opinion appears to be still rather extensively entertained; though the practice of felling in winter has wholly ceased, on account of the encreased value of the bark. But efforts have been made, and supposed to have been successful, to obtain the advantages of both seasons of felling, by taking off the bark in spring, and suffering the tree to stand till the ensuing winter. A good many facts, which had come within my own observation, and information which I received from other sources, had satisfied me that the durability of the alburnum, at least, of oak trees is considerably increased by this mode of management; and I was, consequently, led to make a few experiments (with the result of which I now take the liberty to trouble the Royal Society) with the hope of discovering the cause of this supposed superiority in the quality of the wood of winter-felled trees.

In the spring of 1817, two oak trees, of nearly the same age, and growing contiguously in the same soil, were selected, each being somewhat less than a century old. The one was deprived of its bark, to as great an extent as the inexperience

of my workmen permitted me to have done without danger to them, and it was then suffered to remain standing. The other tree was felled, and, in the usual manner, immediately stript of its bark; and the trunk was then removed to a situation in which it was securely protected from the sun and rain. The following winter, in December, the other tree (which still retained life) was felled, and its trunk immediately placed in the same situation with that of the other tree; pieces of each, selected from similar parts, have been subjected to the following experiments at different subsequent periods.

Small blocks, of similar form and size, were taken from the alburnum of each tree; and after these had ceased to lose weight, in a very warm and dry situation, the specific gravity of each was ascertained; when that of the alburnum of the spring-felled tree was found to be 0,666, and that of the same substance of the winter-felled tree to be 0,565, taking the average of several pieces of each. I had anticipated a loss of weight to about this amount in the alburnum of the winter-felled tree, having inferred, from former experiments, that it must have given out a large quantity of matter in the spring and early part of the summer, to form the leaves and young shoots, which quantity could not have been restored to it during the summer, on account of the descending current of sap through the bark having been wholly intercepted.

Small blocks of equal weight of the alburnum of each tree were divided by cleaving into thin pieces; and these, after having become perfectly dry, were suspended together during ten days, in a somewhat damp room; when 1000 grains of the alburnum of the spring-felled tree were found to have gained 162 grains, and an equal weight of that of the

winter-felled tree 145 grains; and I found that each substance permanently retained moisture nearly in the same proportion that it absorbed it. The alburnum of the oak, as of other trees, therefore, undergoes some change of properties in the spring; and I do not entertain any doubt but that, in all cases in which it is expedient to give durability to that substance, much advantage may be obtained by taking off the bark in spring, and suffering the trees to stand till winter. The durability of the alburnum of large oak-trees of British growth is not, however, generally an object of much consequence; because it almost always lies wholly exterior to the heart wood; but in the oak timber, which is imported from the North of Europe, the alburnum and heart wood are very often intermixed, the growth of ten or a dozen years, or more, of alburnum and heart wood composing, in alternate layers of unequal depth, the whole body of the tree; and the value of the timber of such trees, is probably much affected by the season of felling.

Many experiments, similar to the preceding, were made upon the heart wood, in which I found the disposition to absorb moisture, somewhat greater in that of the spring-felled, than in that of the winter-felled tree; and I scarcely entertain any doubt but that the winter-felled heart wood is the best, and most durable; but I do not think any conclusion can safely be drawn till the heart wood of many trees has been subjected to experiment; and therefore, as I have no evidence to offer which is in any degree conclusive, I shall not at present trespass farther upon the attention of the Society.

Downton,
March 29, 1820.

XI. *On the mode of formation of the canal for containing the spinal marrow, and on the form of the fins (if they deserve that name) of the Proteosaurus.* By Sir Everard Home, *Bart. V. P. R. S.*

Read May 4th, 1820.

The last communication respecting the bones of the Proteo saurus which I laid before the Royal Society, contained so many important facts connected with the skeleton, that there was no room left to hope, I should ever again call the attention of its members to this subject.

Yet such has been the exertion made by some persons employed by Colonel Birch, to explore the cliffs at Lyme, in search of fossil organic remains, from an expectation that they will receive the full reward of their labours, that many new specimens have been lately collected; in one of these which Colonel Birch has submitted to my observation, several bones are met with that have not been described, and which give a very important character to the vertebræ, and also form a more complete set of the bones of the fin. Of these I shall give a description, where their appearance is not sufficiently illustrated by the annexed Plate, (Pl. XV.)

Although the bodies of the vertebræ of this animal have been more frequently met with than any other bones, the manner in which the canal for the spinal marrow is formed, has not till now been made out. In this specimen we find

in what manner that is done, and in this as well as in many other particulars, the skeleton differs from that of other animals.

In all the lizard tribe, the vertebræ, like those of other quadrupeds, consist of a body, two transverse, and one spinous process, surrounding a central hole, which forms the spinal canal; the vertebræ of the different tribes of Proteus have the same structure, as is shown in a Plate annexed to my former Paper upon that subject. In cartilaginous fishes, the mechanism is very different; the bodies of the vertebræ, properly speaking, form the spinal column; and the canal for the spinal marrow is surrounded by separate cartilages, united to the vertebræ, by projections fitted to corresponding notches in the side of each vertebra. Through the whole length of the tail, a similar canal is formed upon the under edge of the vertebræ, in which are contained and defended from injury, the great artery and vein. In the fossil remains of the shark tribe, the bodies of these vertebræ are very frequently met with, and have hitherto been readily distinguished from all others by these peculiarities.

The structure of the vertebræ of the Proteosaurus, is something intermediate between the two kinds which I have described. It is composed of bone, as in the lizard tribe, but consists of a body only, behind which is a canal for the spinal marrow, and the spinous process with two lateral branches which belong to it, quite distinct from the body of the vertebra, and between these there is no bony union, but a species of joint peculiar to themselves; the canal thus formed, defends the spinal marrow from injury, equally as when the whole vertebra is in one piece; it is unusually small. The

bodies of these vertebræ, when met with without the spinous processes, have so close a resemblance to the vertebræ of the shark in a fossil state, that they have till now been mistaken for them; and I found several of them preserved in the HUNTERIAN Collection, marked as belonging to that fish.

The particular structure which I have endeavoured to describe, will be more readily understood by a reference to the annexed Plate, (Pl. XV.) in which it is very accurately represented.

In the same figure in which the manner of setting on the spinous process to the vertebra is shown, there is (what I have never before met with), one of the feet paddles or fins, (for it is difficult to say which of these names is the most proper), in which the bones are nearly complete; for although some of the smallest are wanting, there are quite enough to give a tolerably exact figure of the outline; of this no other specimen has afforded the most distant idea. This outline certainly has more resemblance to that of a fin, than to any of the fore feet of the tribe of lacerta, or the seal, or even the turtle; and, what is the most remarkable circumstance, there is nothing in any way correspondent to the thumb, or claw for laying hold, which distinguishes the animals that occasionally inhabit the sea, and come ashore for the purpose of laying their eggs, or depositing their young. It certainly has the appearance of a fin; but if in future it is to be designated under that name, it is always to be understood that this fin, contrary to every thing hitherto known in nature, is made up of bony materials; and it is from the great number of bones of which it is composed, and the correspondent

number of joints by which these bones are united to each other, that it is enabled to perform the office of any thing resembling the fin of a fish.

In the whale tribe, they are not properly fins, (although they cannot deserve any other name) as they contain the same series of bones as in the seal; and yet no reason can be given why that is the case. In the Proteosaurus, which partakes more of the fish than of the whale tribe, there is probably a greater degree of nicety of adjustment of motion wanted than in the whale, and consequently a greater subdivision of parts, to compensate for the unyielding materials of which these parts are composed; and in this instance there are more than two hundred bones, which must greatly exceed the number of cartilages met with in the fins of the shark.

The facts shown in this specimen, it will be admitted, are of considerable importance, in making us more intimately acquainted with the skeleton of this most extraordinary animal. The second figure contained in the same Plate, (Pl. XV.) is of a less interesting nature, because the parts have been repeatedly shown upon former occasions; and although there is sufficient resemblance of parts to give the idea of this figure belonging to the same skull as the other, on which the facts that have been detailed have their dependance, if that is admitted, much intervening substance must have been lost. In this figure, the teeth are better seen than in any other that I have examined; they are distinctly grooved on their surface up to their points, and are firmly fixed in the jaw, so that they are all preserved in their proper place.

The section of the nose, represented in Pl. XVI. shows that the nostrils are continued on to the point of the nose, and

the section of the teeth determine their mode of growth to be the same as in the crocodile.

At the close of this paper, I have much satisfaction in stating, that the bones of the pelvis, the only ones not yet described, have at last been brought under my observation, in a specimen found at Watchet, in Somersetshire, and lately purchased for the Museum of the Royal College of Surgeons in London. The specimen is four feet six inches in length, and in consequence of the bones having been little disturbed, is in all respects more complete than any other specimen that has been met with. The bones of the pelvis are, however, in this specimen too much pressed upon one another to admit of a satisfactory drawing being made of them; but they resemble so closely those of the crocodile, as to make any representation unnecessary.

All the fossil bones of the proteosaurus which I have described, belong to the same species; but I have seen bones of another species, which differs from this in the following particulars—the upper jaw is much longer, narrower, and comes more to a point; the teeth were so loosely fixed in the jaws, that hardly any are met with in their sockets; that part which had been enclosed by the gum was grooved; the other portion is very slender, has a polished surface, and comes to a sharp point.

The long bone belonging to the anterior fin in both species is as large again as that belonging to the posterior, but both these bones are flatter and longer in the new species; and where articulated with the two small bones of the fin, send a short process between them; there is also a deep notch on the outer or lower side of one of these two small bones.

EXPLANATION OF THE PLATES.

PLATE XV.

This Plate consists of two figures, representing portions of the skull, jaw, and other parts, of the natural size.

Fig. 1. A portion of the skull behind the orbit. The two principal objects in this figure are, the mode of articulation of the spinous processes with the bodies of the vertebræ of the back, forming the canal in which the spinal marrow is contained; and the fin of this animal in the most perfect state yet discovered, one hundred and seventy separate bones remaining in their natural situation.

Fig. 2. Shows the anterior portions of both jaws, which appear from their size to have belonged to the same skull as Fig. 1, having been found in the same situation; allowance must however be made, for a considerable intervening portion having been lost.

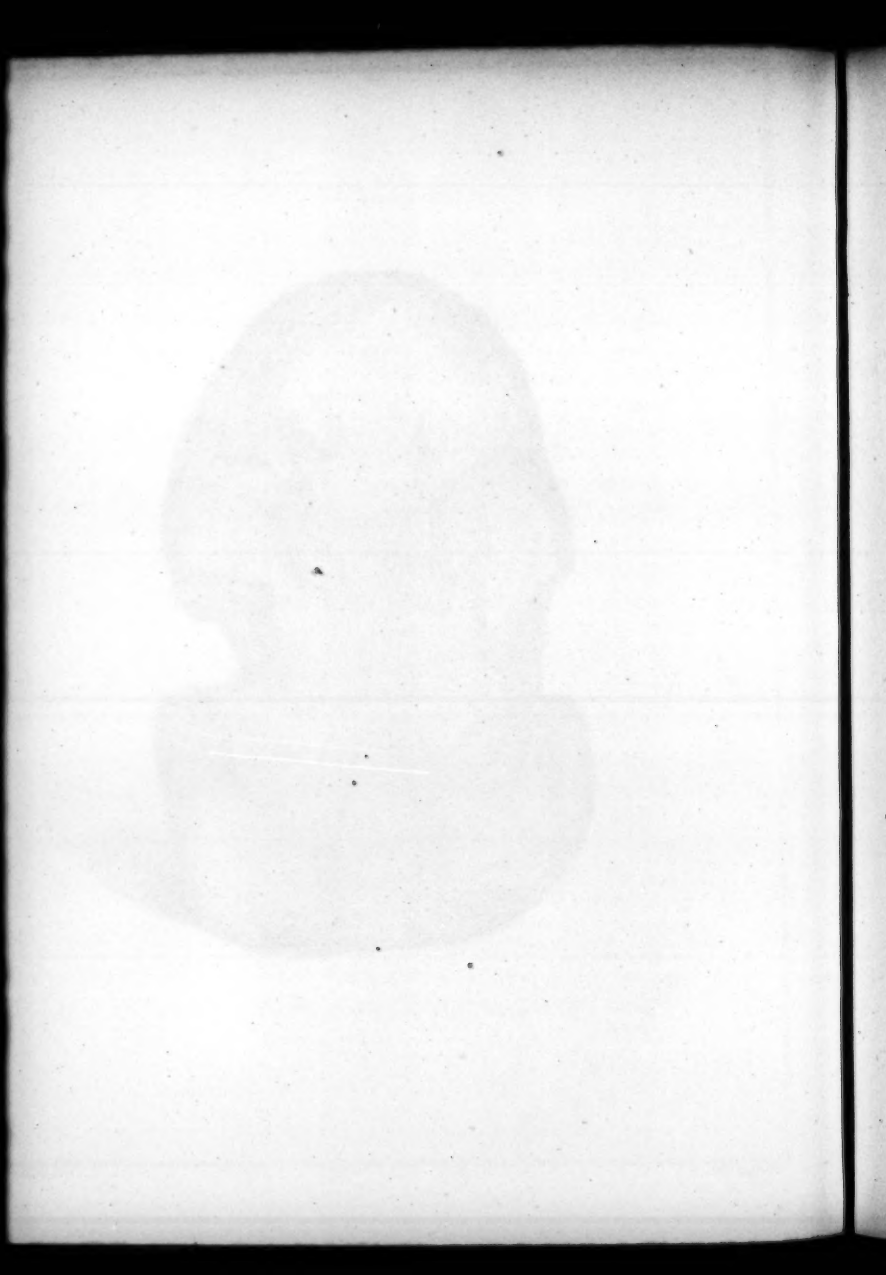
PLATE XVI.

Represents a transverse section of the nasal bones, of the natural size.

This is the only opportunity that has offered of seeing the cavity of the nostrils.

The teeth and their sockets in both jaws were accidentally divided in making the section of the nose, and their internal structure exposed, from which it appears, that the mode of growth is similar to that of the crocodile; the succeeding tooth filling up the cavity of that which preceded it.

Fig. 2.
Fig. 1.



XII. *Some experiments on the fungi which constitute the colouring matter of the red snow discovered in Baffin's Bay.* By FRANCIS BAUER, *Esq. F. L. S. In a Letter addressed to the Right Honourable Sir* JOSEPH BANKS, *Bart. G.C.B. P.R.S. &c. &c.*

Read May 11th, 1820.

SIR,

THE continuance of the severe cold weather, and the frequent falls of snow, during last winter, afforded me ample opportunity for investigating the nature and economy of the fungi, which constitute the colouring matter of the red snow, discovered in Baffin's Bay, on the 17th of August, 1818, during the Northern Expedition, under the command of Captain Ross; and I have now the honor of laying before you, the result of my investigation; and if you should consider it to merit the notice of the Royal Society, I should feel highly honoured by its being communicated to that learned Body, through your favor.

Since the month of March, 1819, I preserved in a small glass, a portion of the original sediment of the red snow, brought from Baffin's Bay, during which time the fungi, which constitute that sediment, had considerably increased in number; but the newly formed fungi remained ever perfectly colourless, and formed a kind of whitish crust, at the top of the red sediment.

With a view to ascertain whether those fungi really vegetate, and propagate in the snow, after draining off the

water, I carefully separated the colourless crust, and taking out of the glass the greatest part of the red sediment (which I intended for another experiment, but which failed, and shall be described hereafter) I filled the glass again with water, and left it at rest for several hours; when the few fungi which were left in the glass, formed a slight sediment of about $\frac{1}{40}$ part of an inch in thickness, at the surface of which the colourless crust, about $\frac{3}{40}$ parts of an inch in thickness, remained. Fig. 1. in the annexed Plate (Pl. XVII.) is a correct representation of the glass, and the quantity and proportion of its contents.

On the 10th of December, 1819, when we had the first fall of snow, I marked with a diamond on the glass the precise height of the mass of sediment it contained, and after carefully draining off the water, I filled the glass with snow, which I pressed in as hard as I could, by which means the fungi became completely mixed and immersed in the snow. Thus prepared, I put the glass into a wire bird cage, to prevent its being disturbed by birds, or any thing else, and placed the cage in a N. W. aspect, in the open air. The weather was then very cold, and on the following morning, the 11th of December, the thermometer was 26 degrees below the freezing point. On the 13th of December the weather suddenly changed and became milder, and about noon the snow in the glass was entirely dissolved; on examination, after the glass had been fifty-two hours in the open air, I found the whole contents had formed a sediment, and had become of the same red colour as the original sediment was; but no increase in quantity was then perceptible; see Fig. 2.

I immediately poured off the water, and filled the glass again with snow, in the same manner as before, and exposed it in the open air, where it remained until the morning of the 17th of December, when a general thaw had begun; on examination I found the snow in the glass was not quite dissolved, but was a lump of ice, perforated, and full of cells, like a honeycomb, and the mass of fungi was raised in little pyramids; see Fig. 3.

From the 17th of December till the 28th, the weather continued very mild, and we had no snow till the morning of the 28th; on that day I filled the glass again with fresh snow; but perceiving a slight increase in a very small portion of fungi that were accidentally smeared on the corner of the mouth of the glass, when on the 13th of December I took out some of the sediment for examination, and sunk the small glass, with its contents, into a larger cylindrical glass, also filled and pressed with snow, to afford to that portion of fungi room for increasing and spreading in the snow; and in that state I exposed the whole in the open air.

From the 28th of December, 1819, to the 10th of January, 1820, the cold and frost continued very severe, but on the latter day, after the glass had been buried fourteen days under the snow, I took it out, to see what change might have taken place during that time; on clearing away the external snow and ice, I found the appearance of the contents of the small glass, exactly as represented in Fig. 4.

The snow was frozen to a hard mass of ice, which was beautifully perforated and full of small cells, and the whole mass of fungi was raised in a pyramidal form, almost to the

mouth of the glass, filling and occupying the perforations and cells in the ice; and from the base of the sediment, innumerable small air bubbles were visibly and rapidly evolving, by whose means, I think, the fungi are raised in the manner they are found during the time that the snow is dissolving. The small portion of fungi in the corner of the glass had also considerably increased, and spread in the snow above the small glass: see Fig. 4.

After making a drawing of the above described appearances, I deposited the small glass again into the larger one, which was filled with snow, as before, and exposed in the open air, where it remained till the 19th of January, 1820, when the weather changed, and a sudden and general thaw set in; after all the snow and ice were dissolved, and the glass stood several hours at rest, I had the satisfaction to find the appearance of the contents of the small glass, exactly as represented by Fig. 5.

If the sediment in the glass, represented in Fig. 5, is compared with that of Fig. 2, it is evident that, (though a considerable portion of the sediment had at several times been taken out of the glass for examination, and by the frequent changing of the water, some loss was sustained) the increase of fungi, within less than two months, has been more than double.

The only difference I observed, on examining the individual fungi of the newly formed sediment, was, that the number of larger than ordinary sized full grown fungi was greater in the newly formed sediment, than I ever found in the original sediment, brought from Baffin's Bay, where the ordinary size of the full grown red fungi is about a $\frac{1}{1600}$ part of an

inch in diameter, and the largest are about $\frac{1}{1200}$ part of an inch in diameter; the number of large fungi, in proportion to those of the ordinary size, is as 1 to 100; but in the newly formed sediment, after the above described experiments, I found many of the larger fungi to be as large as $\frac{1}{800}$ part of an inch in diameter, and the number of large fungi, in proportion to those of the ordinary size, as 1 to 10.

I also found that, notwithstanding the snow in the glass had so frequently been changed, and though the fungi had sometimes been not more than three or four days in the snow, the water, after the snow was dissolved, always acquired the same disagreeable smell and taste as the original water imported from Baffin's Bay.

The above described experiments I attempted to repeat on a larger scale, and for that purpose I employed a glass of about twelve cubic inches in contents. The original red sediment which it contained was about $\frac{1}{8}$ of an inch in thickness; and after marking on the glass with a diamond the precise height of the whole mass, I drained off the water, and divided the sediment in three equal parts; on the 12th of January, 1820, I put the different portions of sediment into three equally sized glasses, which I afterwards filled and pressed with snow, and exposed them in the open air, as in the former experiments.

The first few days, the weather continued very cold and favourable for the experiment, and the appearance in the glasses was the same as in the former experiment. The fungi in some glasses had risen and spread in rays and pyramids of near three inches in length, and the increase appeared considerable and rapid; but during the day of the

19th of January, the weather suddenly changed, and the snow in the glasses entirely dissolved; but the following night it froze again very hard, and two out of the three glasses burst and fell to pieces; the following morning, the 20th of January, it suddenly thawed again; and before I discovered the accident that had happened, a great part of the snow in the glasses was dissolved, and consequently the greatest part of the fungi they contained was lost; however, I collected all the sediment left in the unmelted snow and ice of the broken glasses, and put it into that which remained entire; after the whole was melted, the sediment which then was produced, certainly appeared considerably increased; but the original glass which had been marked with a diamond being destroyed, I could not form a correct estimate; judging however from the previous appearances, I have every reason to believe, that if the accident had not happened, the result of this experiment would have been equally satisfactory as that of the experiment on the small scale.

On the 22d of January I again filled the glass, containing the remains of the sediments of all the three glasses, with fresh snow, and exposed it in the open air as before; but the next day the general thaw began, and after that day we had no more frost nor snow; I left the glass in the open air till the end of the month, when I examined its contents again, and found no particular change in the substance; but within the glass, which was not quite full, round the surface of the water I observed a kind of crust, consisting of a light yellowish green substance, which on examination in the field of the microscope, proved to consist entirely of the same sized and shaped globules as the original red fungi. I imme-

diately decanted the water and red sediment into another glass; when, on examining the empty glass, I found the appearance of the green substance was not only confined to the top of the glass, above the water mark, but I found many very minute clusters scattered, not only over the sides, but also over the bottom of the glass. I filled that glass with melted snow water, and closed it with a bladder, and in that manner I have kept it ever since.

I examined the glass this morning, and find that a considerable increase of the green fungi has taken place since the 31st of January, when I filled it with water; the green substance forms now an entire crust over the whole inner surface of the glass, particularly the bottom, where the new globules now form a sediment that is visible to the naked eye, and the whole glass is now of a greenish tinge. To what cause this change of colour is to be attributed, I cannot guess.

The experiment mentioned in the beginning of my letter as having failed, was owing to an idea I conceived, that the red fungi would vegetate on the surface of the snow; and with that view I filled on the 10th of December, 1819, a large glass cup with snow, pressing it hard, and giving it a perfectly smooth surface, on which I made an impression with a sixpenny piece; the cavity thus produced I filled carefully with the original sediment of red fungi, expecting that on the slightest increase taking place, the fungi must come over the limits thus set them; but the degree of cold at that time was so great, that, soaked in water as they then were, they froze almost before they came in contact with the snow. On examining them the next morning, when

the thermometer was 26 degrees below freezing, I found them of nearly a black colour, and almost entirely raised up, and detached from the snow; and when on the 13th of January the snow dissolved, the mass of fungi sunk to the bottom of the glass, and gradually changed their colour to a dirty brown, being evidently dead.

The same experiment was repeated several times, and the result was always the same. I subsequently collected the different masses of fungi that had been made use of in these experiments, and immersed them in snow, in one glass, and exposed them to the open air, as in former experiments; but though there was no visible change in the appearance whilst they were in the glass, I found, the latter end of January, when I examined them in the field of the microscope, that many new fungi had been produced during the time the dead sediment had been under the snow; and that the newly produced fungi were not only small and colourless, but had also many full grown bright red fungi amongst them. From this circumstance I conclude, that though the excessive cold, and the exposure in the sharp air and wind, may kill the primitive fungi, their seeds still retain sufficient vitality to vegetate and propagate, if immersed in the snow, which appears to me to be undoubtedly the natural soil of those fungi.

The season having passed by, I was unable to make any farther experiments on this subject.

I have the honour to remain, &c. &c.

FRANCIS BAUER.

Kew Green,
May 7, 1820.

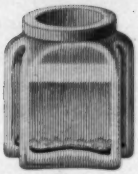


Fig 1.

Fig 2.

Fig 3.

Fig 4.

Fig 5.

For the annexed meteorological diary, I am indebted to Mr. AITON. It is extracted from the diary kept in the Royal Botanic Garden, at Kew, and within 300 yards of the spot on which I made the experiments.

December, 1819.	Degrees of Fahrenheit's Thermometer.			Wind and Weather.	January, 1820.	Degrees of Fahrenheit's Thermometer.			Wind and Weather.
	M 8	A 2	E 8			M 8	A 2	E 8	
December 1	48	46	40	SW Rain.	January 1	10	26½	35	SW Hazy.
2	47	49	38	S Do.	2	19	24	35	SE Rain.
3	26	42	37	SW Fine.	3	32	32	27	NW Snow.
4	41	48	36	SW Rain.	4	20	28½	19	W Cloudy.
5	39	39	36	SW Cloudy.	5	17	28	20	S Hazy.
6	38	36	36	NE Do.	6	22	37	33	S Cloudy.
7	35	34	33	E Sleet.	7	33½	32	26	E Do.
8	31	30	32	E Cloudy.	8	25	30	26	NE Do.
9	24	25	24	E Do.	9	22	28	29	NE Do.
10	30	31	29	E Snow.	10	19	27	26	N Snow.
11	6	24	20	W Fine.	11	27	28½	33	SW Sleet.
12	16	23	25	SW Do.	12	26½	25	12	NE Cloudy.
13	24	36	23	SW Do.	13	10	28	23	NE Do.
14	29	35	31	SW Do.	14	24	27	24	NE Do.
15	32½	38	34	SW Rain.	15	2	21	15	SW Clear.
16	32	39	30	SW Fine.	16	19	22	17	E Do.
17	38	44	46	W Rain.	17	32	35	31	NE Hazy.
18	52	54	50	W Cloudy.	18	27	31	33	NE Snow.
19	51	55	54	SW Rain.	19	47	47	33	SW Rain.
20	53	54	52	SW Cloudy.	20	29	33	32	NE Cloudy.
21	54	54	53	W Do.	21	37	35	33	S Sleet.
22	52	52	51	SW Do.	22	18	30	19	S Clear.
23	49	41	39	W Do.	23	28	33	35	SW Cloudy.
24	29½	36	30	NW Do.	24	38	42	43	SW Do.
25	31	33	28	E Do.	25	42	45	39	S Do.
26	21	34	28	E Do.	26	45	48	45	S Rain.
27	39	32	32	E Snow.	27	48	51	40	S Do.
28	33½	32	31	E Sleet.	28	42	48	38	NE Cloudy.
29	24	28	23	NE Fine.	29	38	44	38	NE Do.
30	14	31½	31	NE Do.	30	40	48	45	SW Do.
31	17	32½	17	NE Do.	31	40	48	42	S Fine.

XIII. *Some account of the Dugong. By Sir* THOMAS STAMFORD RAFFLES, *Governor of Sumatra; communicated in a Letter to Sir* EVERARD HOME, *Bart. V. P. R. S.*

Read May 18, 1820.

MY DEAR SIR,

I HAVE now the pleasure of communicating to you the desired information concerning the dugong. At Singapore, in June last, I had the good fortune to meet with one of these animals, and Messrs. DIARD and DUVAUCEL, two French naturalists, employed under my authority, undertook the dissection of it; and have sent a dissertation upon it to Sir JOSEPH BANKS. This does not interfere with my sending to you, as I promised, an account of it. I was present at the dissection; and the following observations, as far as they go, may be depended upon. I have read them over to Dr. WALLICK and General HARDWICKE, and they concur in opinion as to the correctness of the description. I have the pleasure to acquaint you, that General HARDWICKE has just now got a small dugong, four feet six inches long, which I have succeeded in persuading him to send home to you for dissection, and you will receive it by the next ships.

The dugong which we examined measured eight feet and a half in length, and afforded no less interest under the knife than satisfaction on the table, as the flesh proved to be most excellent beef. Our entertainment was truly marine;

for we had on the same day discovered those Neptunian sponges which General HARDWICKE has since described, and which served us as goblets.

In form the dugong resembles the common cetacea, having, like them, a broad horizontal tail, and two pectoral fins without nails. The skin is smooth, thick, bluish above and whitish beneath, with a few remote and scattered hairs. The mammæ (in the two male individuals examined) are small, and situated on the breast, immediately below the pectoral fins.

Head small in proportion, obtuse, and of a peculiar form. Upper lip very large, thick, and obliquely truncated, forming a short, thick, and nearly vertical kind of snout. The surface of the truncated portion is covered with soft papillæ, and is also furnished with a few bristles. Two short tusks project straight forward from the extremity of the upper jaw, and are nearly covered by the upper lip, which is very moveable, and tumid at the margin. The lower lip is much smaller, and resembles a round or oblong chin. The margin of both lips is furnished with strong coarse bristles. There are no incisors in either jaw (the tusks above mentioned being more properly defences), their place being supplied by the rough bristly surfaces of the palate and jaws, which serve as rasps, to

enable the animal to browse upon the algæ and other submarine vegetables. To facilitate this still farther, the anterior part of the jaw is bent downwards at an angle, in such a manner as to bring the mouth into nearly a vertical direction. There are no canine teeth. The molares are twelve in number, six in each jaw, placed far back on the horizontal part. They are cylindrical, with flat crowns; the first are somewhat oblique, and worn to a kind of point; the second are perfectly flat; but the last are composed of two parallel and adhering cylinders. They are short, and scarcely project from the gums. The tongue is small and short. The nostrils are situated on the summit of the upper jaw, where it makes its curvature downwards. They penetrate obliquely, in such a manner that the upper semilunar edge pressing upon the lower surface, forms a perfect valve. The eyes are small, and situated on the sides of the cranium. The aperture of the ears is so small as with difficulty to be perceived, and is situated at some distance behind the eyes.

Body rounded, diminishing to the tail, and without any vestige of dorsal or ventral fins. The place of the anterior extremities is supplied by fins, which offer no appearance of nails, but are somewhat verrucose on their anterior margin. They are thick and fleshy, and neither from their form nor size capable of supporting or assisting the animal out of the water.

Tail broad, horizontal, and of a crescent or semilunar form.

Dissection.

Skin three quarters of an inch thick, with little adipose matter, and yielding no oil.

The cavity of the abdomen large.

The stomach is large; and the relative position of the cardiac and pyloric orifices is nearly as in the human subject. It has two appendages, which open into it near the junction of the duodenum. Membrane of the stomach thick, internal surface smooth, and not corrugated into plicæ. The stomach and its appendages were distended with fucus or sea-weed, but little masticated or altered. Intestinal canal long. Small intestines uniform. Cæcum very large, somewhat curved, and containing a portion of partially digested sea-weed. Colon exceeding the small intestines in diameter by one third, very uniform, and with few or no contractions. Liver of moderate size, consisting of two large and distinct lobes, connected by a smaller one somewhat tongue-shaped, and a fourth which was very small, on the posterior side. Gall bladder little distended, and situated beneath the third and tongue-shaped lobe. Spleen very small, not exceeding three inches long and one inch thick, attached to the left side of the stomach. Pancreas lying below the duodenum. Kidneys in their usual place, and large. Bladder much contracted, not exceeding the size of an egg, but from the thickness of its coats, is probably capable of much greater distension.

Testicles situated a little below the kidneys, egg-shaped, flattened, partly embraced by a very perceptible epididymis.

Penis large; while collapsed entirely concealed within the prepuce. The glans consists of two lobes, separated or cloven above, in such a manner as to give the whole the appearance of the cloven foot of a ruminating animal. The urethra opens on a small tubercle or papilla between the lobes of the glans.

In the thorax, the thymus gland is particularly large, black and friable under the fingers, and occupying the space between the folds of the mediastinum.

Lungs two, distinct, of an elongated form, not lobulated, and situated posteriorly, one on each side; their substance of the usual mottled colour. The trachea bifurcates very high up, and the two branches diverge to their respective lungs.

Heart situated on the left side, double; that is to say, having the ventricles entirely separate at their points, and only connected at the upper part, or base. Each side possesses a ventricle and auricle, with the usual valves, and without any communication between the right and left sides. The left ventricle, which gives off the aorta, is stronger and more muscular than the right, whose cavity is larger, and coats thinner.

Of the skeleton, a few observations will suffice.—The skull is remarkable by the peculiar manner in which the anterior part of the upper jaw is bent downwards, almost at a right angle, so as to form a kind of beak. The lower jaw is truncated in such a manner as to

correspond, and become parallel with the elongated portion of the upper jaw. This portion of the lower jaw has eight alveolar excavations, which are sometimes empty, and sometimes contain the rudiments of teeth.

The vertebræ are fifty two in number, seven to the neck, eighteen to the back, and twenty seven to the tail.

Ribs, eighteen on each side.

Sternum nearly a foot long, bifurcate at the apex, and articulated to the cartilages of the upper ribs.

There is no pelvis or posterior extremities, but there are found opposite to the eighth or tenth lumbar vertebra two bones, one on each side, lodged in the flesh, which are narrow and flattened, and not above five or six inches in length. Scapulæ broad and thick; humerus short and strong, as is also the radius and ulna. The whole of these are firmly articulated to each other; and though externally the fins offer no appearance of fingers, all the corresponding bones are found complete even to the last phalanges.

The food of the dugong appears to consist exclusively of fuci and submarine algæ, which it finds at the bottom of shallow inlets of the sea. The position and structure of the mouth, enables the animal to browse upon these vegetables, much in the same manner as a cow in a meadow; and the whole structure of the masticating and digestive organs show it to be truly herbivorous. The flesh resembles young beef, and is very delicate and juicy. The individual, of

which the skeleton and intestines are now sent to England, was taken at Singapore, in June, 1819.

According to the information given by the natives, the dugong is never found on land, or in fresh water, but generally in the shallows and inlets of the sea, where the water is only two or three fathoms deep. During our short possession of Singapore, (not more than six months) four of these animals have been taken; but the greatest number is said to be caught during the opposite or northerly monsoon, when the sea is calmest, near the mouth of the Johore river, in the inlet of the sea between Singapore Island and the main. They are usually taken by spearing (at which the natives are particularly dexterous) during the night, when the animals give warning of their approach by the snuffling noise they make at the surface of the water. The first object is to secure and elevate the tail, when the animal becomes perfectly powerless, and at their disposal. They are seldom caught above eight or nine feet in length, but how much larger they grow is not ascertained, as when they exceed this size, their superior strength enables them to make their escape when attacked.

The Ikan dugong is considered by the Malays as a royal fish, and the king is entitled to all that are taken. The flesh is highly prized, and considered by them far superior to that of the buffalo or cow. They distinguish two varieties, the duyong *bumban*, and the duyong *buntal*; the latter much thicker and shorter in proportion. The breasts of the adult females are said to be large. The affection of the mother for its young is strongly marked; and the Malays make

frequent allusion to this animal, as an example of maternal affection. When they succeed in taking a young one, they feel themselves certain of the mother, who follows it to the margin of the sea, and allows herself to be speared or taken with the greatest ease. The young have a short sharp cry, which they frequently repeat; and it is said they shed tears. These tears are carefully preserved by the common people as a charm, the possession of which is supposed to secure the affections of those to whom they are attached, in the same manner as they attract the mother to her young. This idea is at least as poetic, and certainly more natural, than the fable of the Syren's song.

I remain, my dear Sir,

yours truly,

THOMAS STAMFORD RAFFLES.

Dimensions.

	Ft.	In.
Total length of the animal	8	6
Greatest circumference	6	0
Length of the head from the nostrils to the occiput	1	3
——— from the nostrils to the end of the snout	0	3½
Width of the snout	0	9½
Depth of Do.	0	4½
Length of the chin	0	5
Breadth of Do.	0	5½
Distance from the nostrils to the eyes	0	6½
——— the eyes to the ears	0	6½
——— the eyes to the fin	1	5½

	Ft.	In.
Length of the fins	1	4
Breadth of Do.	0	8
——— across the belly from fin to fin	1	11
Distance between the mammæ	1	5
Breadth of tail from tip to tip	2	7
Circumference of the root of the tail	1	9
Distance from the anus to the centre of the tail	2	9
——— from the anus to the penis	1	8
Total length of the intestines	115	0
—— Do. of small intestines including the cæcum	44	0
—— Do. of great intestines	72	0

With this account, Sir T. S. RAFFLES sent me a copy of some observations in French, by Messrs. DIARD and DUVAUCEL, upon the stomach of the dugong. Sir T. S. RAFFLES mentioned that these observations formed part of a Memoir written by those Gentlemen; under these circumstances, I have not felt myself authorized to lay them before the Society, along with those made by Sir THOMAS STAMFORD RAFFLES, which I consider of too much importance to be delayed.

EVERARD HOME.

XIV. *Observations on the Human Urethra, showing its internal structure, as it appeared in the Microscope of* F. Bauer, *Esq. By Sir* Everard Home, *Bart. V. P. R. S.*

Read June 1, 1820.

The smallest additions to our knowledge of Human Anatomy, have ever met with the most liberal reception from the Royal Society. Such communications must necessarily be of rare occurrence, the field having not only been gone over so often, but cultivated with the utmost labour and zeal, by men of the highest talents, and most acute discernment. Much, however, is still wanting to make us acquainted with the internal structure of all the organs of the human body; and some of those not yet thoroughly examined, are of very great importance, not only on account of the functions they perform, but the diseases to which they are liable; since by these diseases the natural functions are disturbed, and occasionally completely interrupted; and when that happens, the life of the patient is too often destroyed.

The structure of the human urethra, as far as it could be examined by ordinary vision, assisted by glasses of small magnifying power, has been long known to all the anatomists of the present day; and twenty-five years ago I thought myself thoroughly acquainted with it; but I now find that I was wholly ignorant of the more minute parts of its conformation.

For the knowledge I have now acquired, which it is the

the object of this paper to communicate to the Society, we are indebted to Mr. BAUER, who has given the most patient and laborious attention to the examination of these parts, magnified in different ways, and has faithfully represented them as they appeared to his view.

From Mr. BAUER'S examinations, we find that the human urethra is made up of two parts, an internal membrane, and an external muscular covering.

The internal membrane is exceedingly thin, and no fibres are met with that can give it a power of contraction. When it is put on the stretch in a transverse direction, the circumference of the canal is no ways encreased; but when stretched longitudinally, a small degree of elongation is produced.

When a transverse section of the urethra is made while in a collapsed state, the internal membrane is found thrown into folds pressed together by the surrounding parts. This appearance is shown in the most satisfactory manner in the annexed Plates.

On the surface of the internal membrane, over which the urine passes, there are numberless small projections, or papillæ, the orifices of glands. The surface is covered with small blood-vessels, and the lacunæ leading to the deeper seated glands, are very numerous. These parts are beautifully represented in Plate XXI. Fig. 4, in a small portion of the lining of the urethra, near the external orifice, minutely injected, magnified ten times in diameter.

The muscular covering by which the membrane is surrounded, or enclosed, is made up of fasciculi of very short fibres, which appear to be interwoven together, and to be

connected by their origins and insertions with one another; they all have a longitudinal direction. A muscular structure of this description, as far as I know, is not met with in any other part of the body. It is however to be observed, that there is no other instance in which fibres of such minuteness have been examined, and faithfully represented.

There is a greater thickness of this muscular structure upon the upper, than the under surface of the urethra, which is still more evident, as it approaches nearer to the external orifice. The fasciculi are united together by an elastic substance of the consistence of mucus. This muscular structure is represented in a longitudinal section of a portion of the corpus spongiosum urethræ, magnified fifteen times in diameter. The internal structure of these fasciculi is shown in Pl. XXIII. Fig. 2, 3, magnified twenty-five diameters, and in Fig. 4, magnified fifty diameters. In this Plate the fasciculi are thickened in consequence of inflammation. Immediately beyond the muscular portion of the urethra, is the cellular structure of the corpus spongiosum.

This mechanism, which forms the canal of the urethra, is very different from what it has hitherto been contemplated to be, and therefore a knowledge of it enables us to correct many errors that we had fallen into with respect to the actions of its parts, both in a healthy state, and when under the influence of disease.

Till now it was believed, that either the lining of the urethra was composed of circular fibres, possessed of a power of contraction, or that it was immediately surrounded by such fibres; and therefore, that the disease commonly known by the name of a stricture in the urethra, was produced by a

contraction of some of these circular fibres; and that permanent stricture was a term applied to these parts, when, in consequence of inflammation, they became confined to that particular state.

We now find from the annexed Plates, that the lining of the urethra is never met with in a contracted state, but is thrown into folds by the action of the elastic ligamentous covering of the corpus spongiosum, and the swell of the longitudinal muscular fibres within it; and when these fibres have, by acting through their whole length, reduced the urethra to its shortest state, the pressure upon the internal membrane is so great, that there is not room for the urine to pass till these fibres are relaxed by elongating the whole canal.

A spasmodic stricture is in reality a contraction of a small portion of the longitudinal muscular fibres, while the rest are relaxed; and as this may take place either all round, or upon any one side, it explains what is met with in practice, and which could not be satisfactorily accounted for; the mark or impression of a stricture sometimes forming a circular depression upon the bougie, at others only on one side.

A permanent stricture is where, in consequence of inflammation, coagulable lymph is exuded, between the fasciculi of muscular fibres, and upon the internal membrane, in different quantities according to circumstances; and in the same proportion diminishing the passage for the urine at that part, or completely closing it up. The changes the parts undergo in the formation of a permanent stricture, are most satisfactorily shown in Pl. XXII. XXIII.

In this investigation, Mr. BAUER'S examinations have not been confined to the canal of the urethra; he has, at my

request, extended them to the corpus spongiosum, and to the corpora cavernosa; respecting the structure of which, even at this day, different opinions are entertained by some of the most celebrated physiologists in Europe.

When these bodies are entirely empty and collapsed, as we generally find them in the dead body, they contract so much from their elasticity, as to make it next to impossible to examine the structure of their different parts; and no inconsiderable art and contrivance becomes necessary, so to prepare them, that the internal structure, may be sufficiently displayed, to render the examination satisfactory. Every attempt to make the substances commonly used as injections, pass from the arteries into the cellular internal structure, proved ineffectual; that mode therefore of distending those cells was soon abandoned; injecting them directly by puncturing the surrounding coverings, could not give them their natural appearance; we therefore did not avail ourselves of it. The only mode of expanding the internal structure, at the same time that it was not disturbed, was to fill it through the medium of its own arteries, and then, by hardening the parts in spirit, preserve them in a distended state.

This was done in three different ways. In one instance they were found filled naturally, by the blood that had been retained there, and which, in the act of dying, had not been expelled, as in Plate XVIII.

In another, proof spirit was injected by the arteries till all the internal cellular structure was distended by it; and this spirit was retained there, as in Plate XIX.

In a third, the arteries were injected with quicksilver, which readily passed into the internal parts, and was retained

there by plugging up the trunks with common injection. The parts were then dried, and put into oil of turpentine. When preserved some time in that state, a longitudinal section of one of the corpora cavernosa was made, as in Plate XX, and the quicksilver allowed to run out. The preparation thus made is in the Collection of the Royal College of Surgeons in London; one of the many valuable donations made to that Museum by Sir WILLIAM BLIZARD. The others were made upon this occasion.

From these preparations, the fact is sufficiently established, that the cellular internal structure of the corpora cavernosa and corpus spongiosum, receives the blood into its cavities directly from the smaller branches of the arteries with which these parts are provided; but the nature of this structure remains to be explained.

It was found by Mr. BAUER, from an examination of these different preparations, that the cellular structure of the corpora cavernosa is made up of an infinite number of thin membranous plates, exceedingly elastic, so connected together as to form a kind of trellis work, the edge of which is firmly connected with the strong elastic ligamentous substance by which these bodies are surrounded, and which forms a septum between them, separating them from one another. This substance has an intermixture of muscular fibres. The septum has not the same appearance in different individuals; in some, it is much thicker than in others; and towards the anterior end, in one preparation, was almost entirely wanting; as in Plate XVIII, Fig. 2.

In the central line of each corpus cavernosum there is an open space. This is of considerable length, but is by no

means equally so in different instances. This has no regular boundary, and appears to be formed simply by the elastic plates being wanting. These plates, from their extreme elasticity, are with difficulty examined; but as it appeared that their structure is the subject respecting which physiologists are not agreed, Mr. BAUER spared no pains, and exerted his ingenuity in putting them to the test of different modes of examination on the field of the microscope, and is perfectly satisfied that they are what he has represented them to be; namely, simple thin membranous elastic plates, not made up of more than one layer, not having a cavity between them, nor in any way forming regular cavities, but having irregular interstices: they vary in size considerably in different parts of the same body. It is into these interstices that the blood is occasionally received from the termination of the small arteries which are every where branching upon, and supported by, the elastic plates of which the trellis work is composed; as in Pl. XVIII, Fig. 1. Pl. XIX, Fig. 1. Pl. XX, Fig. 1.

The circulation of the blood in these parts being different at different times, is a most beautiful illustration of the fact, which upon a former occasion I communicated to the Society; namely, the great influence the nerves have upon the action of the smaller arteries, as well as on their larger trunks. When the nerves that supply the corpora cavernosa and corpus spongiosum, (and they are very numerous,) are not affected by the state of mind of the individual, the blood is not carried into this trellis work, but returns by the veins, as in other parts of the body; but when the mind receives such impressions as excite these nerves, the smaller arteries have their action so much

increased, as not only to pour the blood into the interstices, and the open space which they inclose, but to distend them, overcoming the elastic power that, under ordinary circumstances, keeps them collapsed.

The corpus spongiosum differs in nothing from the corpora cavernosa, but in the parts being formed upon a smaller scale; there being no open space in the middle or central line of the trellis work; and the ligamentous elastic covering which surrounds it, having no muscular fibres intermixed with its substance. When a transverse section of the corpus spongiosum is examined in the microscope, the orifices of six or seven divided arterial trunks are distinctly seen in different parts of the section, as in Pl. XXI, Fig. 1.

As the corpus spongiosum may be said to be continued into, and to form the glans, the internal structure of which is of the same kind, I was desirous that Mr. BAUER should examine the covering of that body in the microscope, to ascertain whether there were any papillæ upon its surface, so different from those of the skin generally, as to account for this part having a sensation peculiar to itself, and as unlike the common feeling of touch, as the sense of taste, which is peculiar to the tongue; this last I have explained upon a former occasion to the Society, is confined to the tip; since, when the sense of taste is destroyed by the nerves that produce it being injured, the common sensations of the rest of that organ, as well as its voluntary motions, are as perfect as before.

From the annexed magnified representations of a portion of the glans, showing the papillæ on its surface, it is evident that such a peculiar organization must be constructed to produce a more than ordinary delicate sensation. Pl. XXI, Fig. 5, Fig. 6.

To describe the appearance which is so beautifully represented in the drawing, would be trifling with the time of the Society; and I am afraid that I have already allowed myself to say much more upon several of the other subjects contained in this paper than was necessary, illustrated as they are by Mr. BAUER's drawings.

EXPLANATION OF THE PLATES.

PLATE XVIII.

Consists of two figures or transverse sections of the same penis, magnified four times in diameter.

Fig. 1. Shows the internal structure of the corpora cavernosa near the middle of the penis, where the central part is one general cavity, surrounded every where by the open trellis work; the interstices are filled with coagula of the blood they contained at the time of the person's death; the divided trunks of the arteries which supplied the blood are very distinct.

Upon the dorsum penis are seen the divided arteries which lie there, imbedded in the elastic ligamentous and muscular substance, by which the corpora cavernosa are covered, and which is continued between them, forming the septum; it also completely surrounds them.

The cellular structure of the corpus spongiosum forms a similar trellis work upon a smaller scale; the urethra passes through it rather above the centre. The lining is thrown into folds, and the opening, which is closed, is flattened, being more compressed from above and below than laterally.

Fig. 2. The same parts shown in a section nearer the glans. The trellis work here is more distended with blood.

In this section the septum is in part wanting, the muscular coat of the urethra is thinner, and there is no open space in the centre of the corpora cavernosa.

PLATE XIX.

Consists of four figures, taken from a penis in which the corpora cavernosa and corpus spongiosum had been injected by the arteries with spirit, and then allowed to harden in spirit; the urethra had also been injected with spirit, and kept distended.

Fig. 1. This section was taken near the root. The parts are nearly the same as in the last Plate; they are only magnified two diameters.

Fig. 2. A very small portion of the trellis work of one of the corpora cavernosa of the same section; magnified fifteen times in diameter.

Fig. 3. Another transverse section nearer the glans, magnified two diameters. In this the cavity in the corpora cavernosa is seen, and the membrane of the urethra is thrown into folds.

Fig. 4. A very small portion of the last section; magnified fifteen times in diameter.

PLATE XX.

Consists of three figures, taken from a penis, the corpora cavernosa of which were injected with mercury by the arteries, and the mercury was retained there by plugging up the trunks with common injection. The parts were then dried, and a longitudinal section made so as to let the mercury escape and leave the trellis work empty. In this state the preparation is kept in oil of turpentine.

Fig. 1. A longitudinal section of one of the corpora cavernosa, showing the course of the artery, branching through the trellis work. The part at A, has the central cavity exposed. This section is magnified two diameters.

Fig. 2. A very small portion of the cellular substance of the same longitudinal section, taken from the part at A; magnified fifteen times in diameter.

Fig. 3. A small portion near B; magnified fifteen times in diameter.

Plate XXI.

Consists of six figures, three of the corpus spongiosum urethræ, one of the internal membrane of the urethra, and two of the villi of the covering of the glans penis.

Fig. 1. A transverse section of the corpus spongiosum urethræ, taken from the same penis as Plate XIX, Fig. 1. magnified four diameters, to show the parts more distinctly, particularly the sections of the arteries going to the trellis work.

Fig. 2. A small portion of the transverse section, Fig. 1, magnified fifteen diameters, to show the trellis work in the corpus spongiosum.

Fig. 3. A longitudinal section of the same corpus spongiosum and muscular coat of the urethra; magnified fifteen times.

Fig. 4. The internal membrane with the glands upon its surface, and the lacunæ; magnified ten diameters.

Fig. 5. The covering of the glans penis for the papillæ; magnified ten diameters.

Fig. 6. A smaller portion; magnified twenty-five diameters.

PLATE XXII.

This Plate contains two figures, giving different views of a stricture in the urethra. The stricture had become so narrow, that a piece of gravel was prevented from passing, and had imbedded itself in a cul de sac immediately behind the stricture. This piece of gravel increased in size by receiving additions from the urine that passed over it; and the stream, every time of making water, turning it round in its bed, it acquired a spherical form. The patient never having had any attempts made for his relief, and being seized all at once with a complete suppression, died; after death, the calculus was found closing up the orifice of the stricture. Both figures are magnified five diameters.

Fig. 1 A transverse section of the urethra a little beyond the stricture, showing from behind the aperture which the stone closed up, and giving a side view of the cul de sac in which it had usually remained. This cavity is not made by a fold of the internal membrane, but by an exudation of coagulable lymph forming a sac.

The other parts are the same as have been already described in the transverse sections of the urethra, in a natural state.

Fig. 2. Represents the urethra laid open from above, in a longitudinal direction. The right hand portion exhibits the newly formed coagulable lymph produced by the irritation of the stone; the serrated processes of coagulable lymph projecting from the internal membrane, which is itself thickened, and pressed forward by the swell of the muscular structure surrounding it, are also distinctly seen. The na-

Fig. 1.

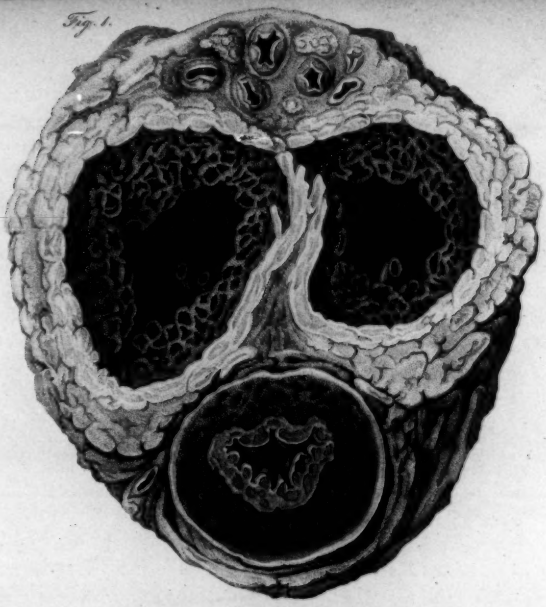


Fig. 2.

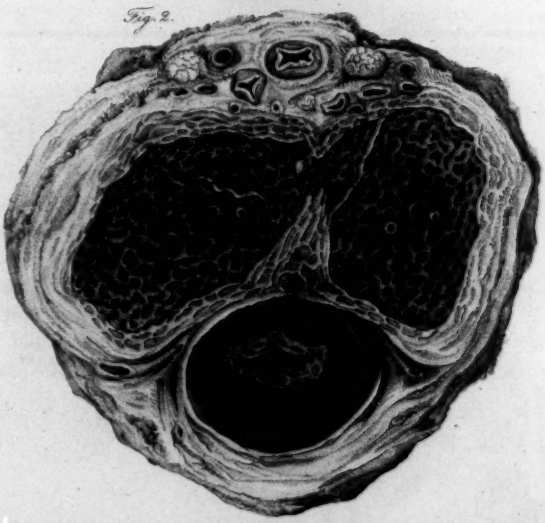


Fig. 1.

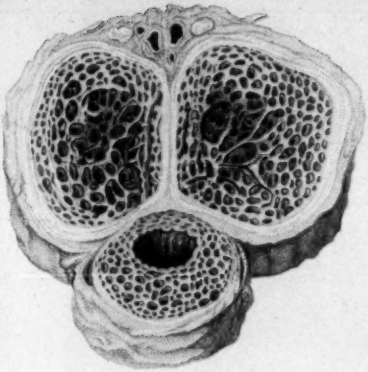


Fig. 2.

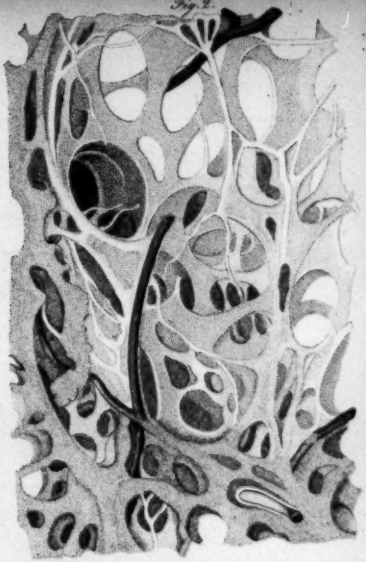


Fig. 3

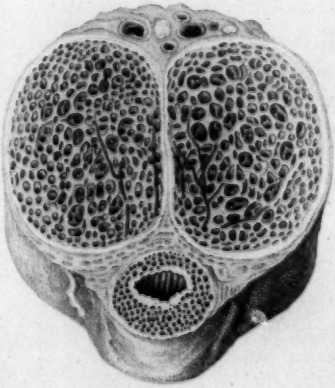
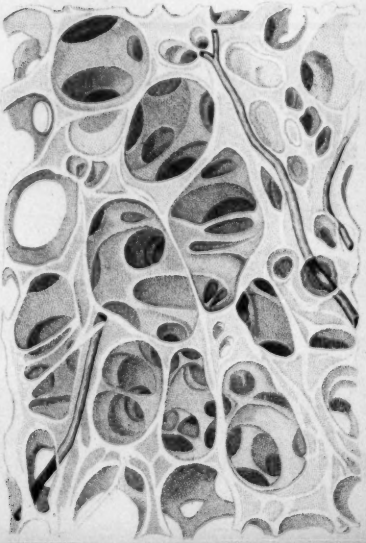


Fig. 4.



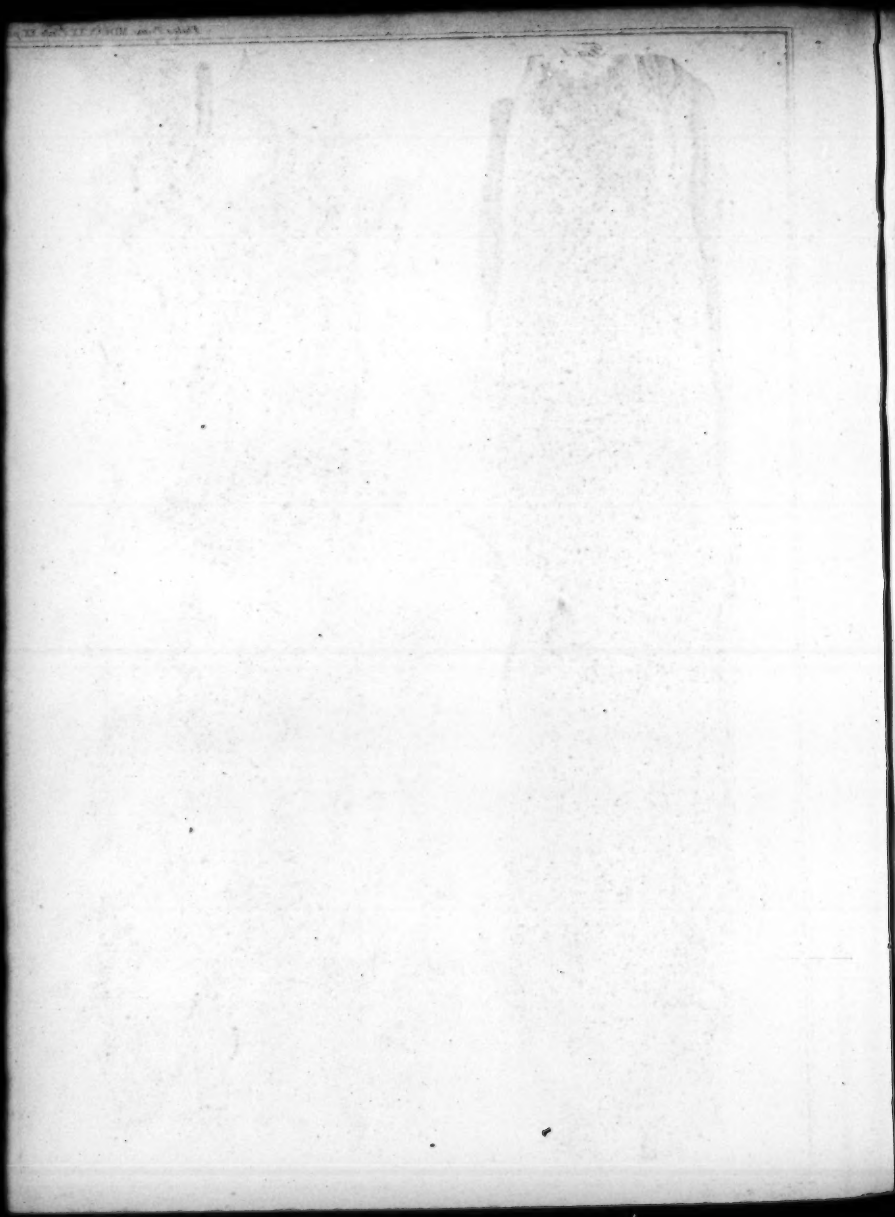


Fig. 1.

A

B

Fig. 2.

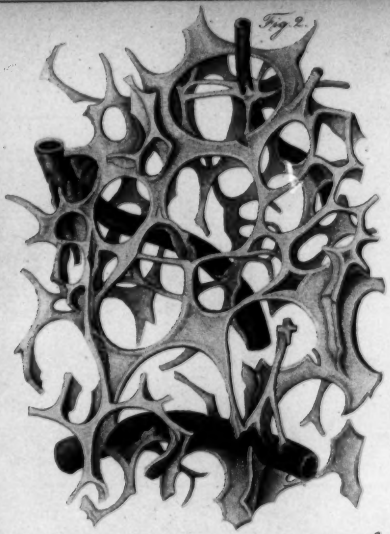


Fig. 3.

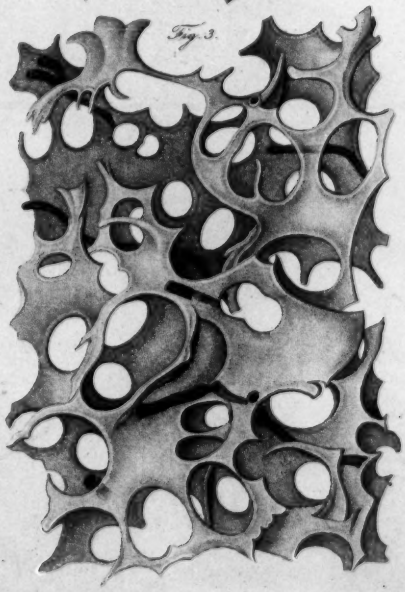


Fig. 1.

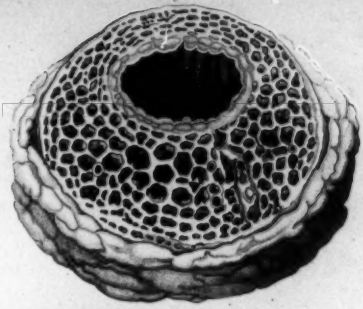


Fig. 2.

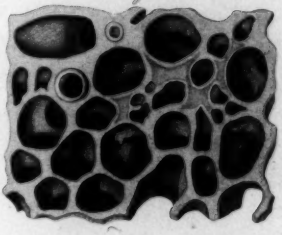


Fig. 3.

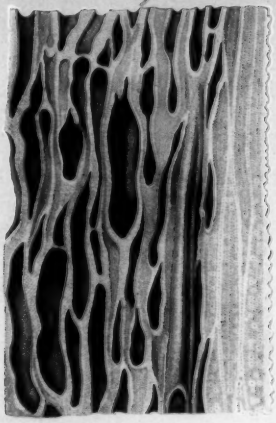


Fig. 4.

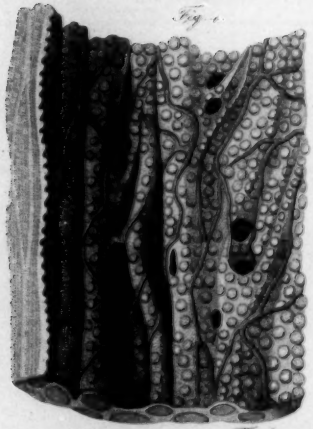


Fig. 5.

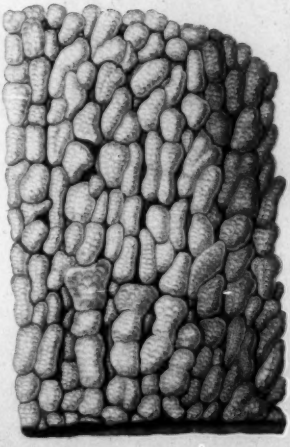


Fig. 6.

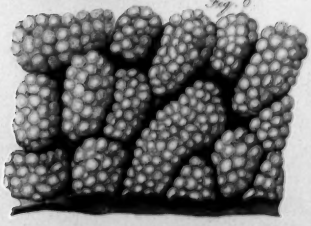


Fig. 1.

Fig. 2.

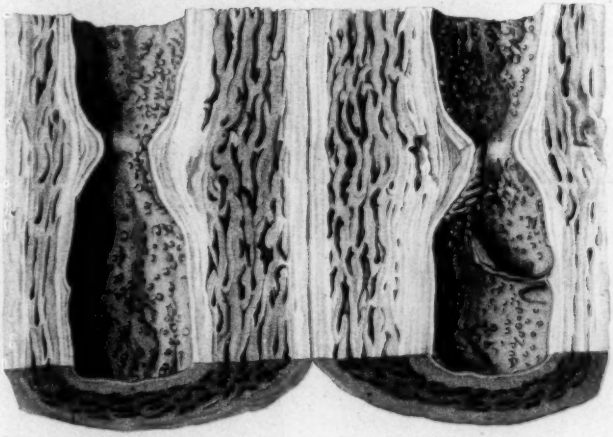
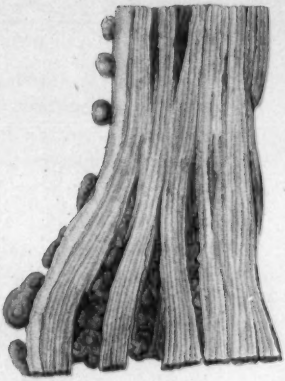


Fig. 1.

Fig. 2.



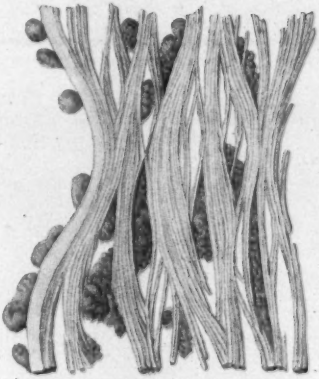


Fig. 3.

Fig. 4.

Franz Bauer del.

J. Basire sc.

tural granulated structure of the internal membrane is increased in size by the effects of inflammation. Besides which, there are small globular exudations of coagulable lymph, like studs, on different parts of the surface.

Plate XXIII.

This Plate contains four figures, representing the internal membrane, and the muscular structure surrounding it, at the strictured part. The three first figures are magnified twenty-five diameters, the fourth fifty.

Fig. 1. Shows the exudations of coagulable lymph in masses of different forms and sizes, and the enlarged glands, nearly uniform in their shape, and of a smaller form.

Fig. 2. Shows the longitudinal muscular fibres, and the masses of coagulable lymph deposited between the fasciculi, increasing the volume so much, as to produce the narrow aperture or stricture.

Fig. 3. The same muscular fibres, having the fasciculi more separated from one another.

Fig. 4. The same fasciculi separated still more, and nearly into their ultimate fibres.

XV. *On the Errors in Longitude as determined by Chronometers at Sea, arising from the action of the iron in the ships upon the Chronometers.* By George Fisher, *Esq.* *Communicated by* John Barrow, *Esq. F. R. S.*

Read June 8, 1820.

The determination of the longitude at sea by timekeepers, is so exceedingly easy from the simplicity of the observations and calculations employed, and from the general practicability of the method, as to render chronometers, in the present improved state of navigation, almost indispensable articles in the equipment of ships for foreign service; and I shall feel happy if the following observations may, in any way, contribute to the more accurate determination of the longitude by this method.

The sudden alteration in the rates of chronometers when taken on board of ships, has been frequently observed by intelligent seamen; and is generally ascribed to the motion of the vessels. Before, however, I attempt to account for this alteration, I shall first prove that it actually takes place; and, in order to do this, shall relate the circumstances connected with the chronometers on board the Dorothea and Trent, commanded by Captain Buchan, which occurred during the late voyage to the North Pole.

Soon after the arrival of the ships on the coast of Spitzbergen, the chronometers on board the Dorothea (five in number) were found to be rapidly gaining on their former

rates as determined in London previous to the ship's sailing; in consequence of which the land appeared considerably to the westward of its true position as determined by lunar observation, and they were found to be still gaining daily, which appeared not only from each subsequent set of lunars, but also by comparing the longitude of different points of land determined by the chronometers, with the longitude of the same points ascertained in the same way some time afterwards.

For instance; the longitude of a remarkable point of land on the north-west coast of Spitzbergen, called Cloven Cliff, was found by a mean of the observations taken with the chronometers on June 21, 1818, to be 10° 35′ 27″ E; but the longitude of the same point of land on July 31, was 10° 15′ 37″ E, making a difference of no less than about 20′ of longitude in five weeks; that is, estimating the longitude with the same rates and errors as determined in London before their departure; from this, therefore, it appears, they had been gaining on their former rates, or had been increasing their gaining rates, and diminishing their losing ones.

An opportunity soon afterwards occurred of observing the effect produced upon the chronometers by removing them on shore. On the 9th of August, the chronometers, nine in number, were landed on an island, where a temporary observatory had been erected for the purpose, and the latitude of which had been accurately determined with a repeating circle made by TROUGHTON, when it was found that the acceleration immediately ceased; for the longitude of the place by chronometers, August 12, was 9° 42′ 36″ E, but on the 27th, it was 10° 1′ 0″ E, making a difference of 18′ 24″ of longitude in fifteen days, using the former rates.

Since, therefore, the chronometers were *getting easterly*

by their removal on shore, the acceleration must have ceased; which will appear upon consideration.

A similar circumstance was observed by Lieut. FRANKLIN to take place with the chronometers on board the Trent, which were four in number; and he observes, "It may be "worthy of remark, that the chronometers taken out by the "Hon. Captain PHIPPS, showed too great westerly longitude, "and consequently gained on these seas. The fact of so "many chronometers altering their rates the same way, is "curious, but I am not aware that any cause can be as-"signed."

The effect produced upon one or two of the chronometers by their removal to land, was very remarkable; a chronometer made by BAIRD was (by observations taken on shore near where the ships lay at anchor, by Lieutenants FRANKLIN and BEECHEY, with false horizon, and eight inch reflecting circles of TROUGHTON, from August 8, A.M. to 12, P.M.) losing 3,"4 daily when on board; but upon its removal on shore to the observatory, its rate per transit, from August 16, to 26, was observed by myself to be 18,"2 losing. Upon again removing it on board, it was found by observation, as before, to be losing 6,"5 daily; from which it appears the chronometer lost no less than about thirteen or fourteen seconds daily by its removal on shore.

Another chronometer in the Trent, made by PENNINGTON, had been gaining rapidly on board; when taken on shore, it acquired immediately a losing rate of 1,"8, nearly the same as it had in London before the vessels sailed.

A chronometer of my own, by ARNOLD, was affected likewise nearly as much, losing about 9" daily by its removal on shore.

In the other chronometers the alteration was less sudden, but was ultimately not less considerable; and they were several days on shore before they acquired a steady rate, as will appear by the following table of their rates, during the interval of the respective dates.

Table of Rates of Chronometers immediately when landed, August 9th, 1818.

	No. 1. Earnshaw.	2. Arnold.	4. Barraud.	3. Arnold.	Clock.
August 9	+12,0	−0,2	+8,1	−33,5	
11	+10,2	0,	+7,9	−34,2	
12	+ 7,98	−1,85	+0,8	−36,2	+70,60
16	+ 6,2	−5,1	+7,1	−46,9	+69,03
20	+ 5,63	−5,2	+2,8	−37,7	+ 69,12
23	+ 4,02	−6,14	+4,3	−41,5	+69,29
26					

The rates from August 12 to 26, were determined by the sun's transit, and those from August 9th (the day on which the chronometers were landed) to the 12th, by a comparison with the clock, supposing its mean rate +69,″5, as no observation occurred during this interval; and by this table it appears, that the chronometers when landed were rapidly diminishing their gaining rates, and increasing their losing ones. In the others the effect was almost immediate.

The clock and chronometers were likewise landed upon a small island in Fair Haven, on the north coast of Spitzbergen, on the 30th June; and, as the same circumstances occurred, it will be needless to detail them.

The following table is intended to show the difference

between the rates on board the ships and what they would have been had they been on shore.

Chronometers.	Error, Greenwich time.	Difference.	Interval.	Mean Rates at Sea.	Mean Rates on Shore.
			days.		
No. 1. Earnshaw.	April 11, + 7.40.1	+ 18.52.1	136	+ 8.0	+ 3.8
	Aug. 25, + 26.32.2				
2. Arnold.	April 11, — 0.42	— 3.33	136	— 1.5	— 5.2
	Aug. 25, — 4.15				
3. Arnold.	May 7, — 1.44	1.52	56	— 2.0	— 6.5
	July 2, — 3.36				
4. Barraud.	April 1, — 0. 1	+ 5.56.5	146	+ 2.5	+ 1.2
	Aug. 25, + 5.55.5				
5. Arnold.	April 15, — 0.38	— 28.10	132	— 12.8	— 22.4
	Aug. 25, — 28.48				
6. Earnshaw.	April 11, + 1.13	— 1.10.8	136	— 0.5	— 0.93
	Aug. 25, + 0. 2.2				
7. Pennington.	April 11, + 0. 53	+ 13.3.5	136	+ 5.8	— 0.63
	Aug. 25, + 13.57				
8. Arnold.	April 13, — 0.24	+ 16.17.5	134	+ 7.3	— 2.5
	Aug. 25, — 15.53.5				
9. Baird.	April 15, + 0.25.1	+ 4.47.4	132	+ 2.2	— 5.15
	Aug. 25, + 5.12.5				

The errors of the chronometers in April, were those obtained in London before the ships sailed; those on the 25th August were determined at the Observatory on Dane's Island, Spitzbergen, the longitude of which was determined by a great many observations of the distances of the sun and moon for several days with TROUGHTON's eight inch sextants and reflecting circles. The rates in the column entitled "Mean Rates at Sea," are deduced by dividing the difference of the errors by the interval.

The rates in the column entitled "Mean Rates on Shore," or more properly what they *would have had*, are means between the rates of chronometers on shore before leaving England, and those obtained at Spitzbergen; and although a mean between the rates of chronometers obtained at different times, may not accurately be the mean rate they would have had during the interval of those times, from the continued variation to which they are subject; yet, upon comparing the two last columns together, of the rates thus deduced, it will be perceived, that in all the chronometers their gaining rates had either been increased, or their losing ones diminished on ship-board, or in other words, they had all been accelerated.

Nor is this acceleration peculiar to high latitudes; it was observed very soon after the chronometers were put on board in the River, particularly in Nos. 3 and 8, which, upon arriving at Shetland, were found to have gained instead of losing rates, which they had in London.

This acceleration was very soon perceptible in the chronometers taken out by the Hon. Captain PHIPPS, made by

KENDAL and ARNOLD. Mr. LYONS, who accompanied him, landed at Sheerness Fort, and found the longitude by them to be 30′ 0″ E, which is about 13′ W of the true longitude, as determined in the Trigonometrical Survey.

The same occurrence took place last summer (1819). The longitude of a place in one of the Orkney Islands, as determined by three chronometers made by ARNOLD, two of them belonging to myself, the other to Lieut. E. HOME, R. N. who accompanied me, was 6′ 40″ W, of the longitude determined by the difference of ☊ of stars E and W of ☽.

Again, in the trial of Mr. HARRISON's timekeeper, in 1764, the longitude of Barbadoes by the watch was 10′ 45″ more to the westward than that determined by astronomical observations made by the persons sent out for that purpose.

Soon after this trial, the commissioners of longitude agreed with Mr. KENDAL, one of the watchmakers appointed by them to receive Mr. HARRISON's discoveries, to make another watch on the same construction, which went considerably better than Mr. HARRISON's. Mr. KENDAL's watch was sent out with Captain COOK in his second voyage towards the South Pole and round the world, in the years 1772-3-4 and 5, "when the only fault found in the watch was, that its rate of "going was continually accelerated."

It now remains, therefore, to determine what this acceleration arises from. That it does not arise from the motion of the vessels, is evident in the case of the nine chronometers on board the Dorothea and Trent; since the acceleration was observed when the ships were firmly beset with ice; also in the case of the alteration in the rates of the chronometers upon

landing, and taking them on board again at Dane's Island, the ships were riding at anchor close in shore without any perceptible motion.

An account was also kept on board and on shore, of the state of the temperature and barometer, every two hours, both night and day; and upon comparing them together, there does not appear to be the least correspondence between the change of rates and the temperature at the time.

It appears therefore to me, that this acceleration arose entirely from the magnetic action exerted by the iron in the ship on the inner rim of the balance, which is made of steel.

That the iron in the ships becomes magnetic, is plain, from the polarity which exists in it; the whole forming altogether one large magnet, having its south pole on deck nearly amidships, and its north pole below. This is seen from the constant deviation of the north end of the compasses placed on deck towards the centre of the ship, as appears from recent observations, which I have mentioned elsewhere.

Nor is it surprising that the force exerted by the ship's iron (thus become magnetical) on the balance of the chronometers, should be sufficient to cause a very sensible alteration in the rate of going, when we consider how easily, in other cases, the presence of any thing magnetical is detected by the alteration of the rate of a chronometer; and when we consider the great influence exerted by this iron upon the binnacle compasses at very considerable distances, and in situations where the utmost precaution is used to remove every piece of iron from them, by using copper-bolts, fastenings, &c.

It remains only to determine, how far this alteration in the

rates of the chronometers, can be reconciled with that observed in chronometers when under the influence of magnets placed in different positions with respect to their balances.

To determine this, two watches were used, with steel balances and horizontal escapements, one by EARNSHAW, the other by ALLAN and CAITHNESS; also two chronometers made by ARNOLD. To each of these watches were applied, at a distance of two inches from the balance, magnets of twelve inches in length, in four different positions, and in the planes of the balances.

The following Table will show the rates of the watches in twenty-four hours, deduced by comparing them with an excellent clock with GRAHAM's dead beat escapement, and regulated by transit.

	No. 1.	No. 2.			No. 3.	No. 4.
N	+9.15	+5. 0	3	N	+0.34	+0.41
S	+8.12	+21.0		S	+2.18	+0.44
N	+ 8.0	+18.0	6	N	+1.28	—1.43
S	+48.0	+ 8.0		S	+5.27	—0.36
N	+47.10	+17. 8	9	N	+5.22	+1. 3
S	+72. 0	+ 8.44		S	—0.14	+0.41
N	+4.14	+ 4.32	12	N	+2.47	+1.12
S	—2. 0	+15. 0		S	—1. 2	+1.24

The first column in this table shows the pole of the magnet applied to the watch; the second and third, the rate or effect produced on each watch; the fourth column shows the figure on the face of the watch opposite to which the magnet was applied.

The watch, No. 1, gained with both poles, and in every position of the magnet but one. No. 2, gained with both poles in every position. Nos. 3 and 4 gained in every position but two; and the quantities lost in the positions were far exceeded by the accelerations caused by the opposite poles, excepting one case in that of No. 4.

The magnets were likewise placed in different positions out of the planes of the balances; the results were very *similar* to those above, but differing in quantity, according to the distance of the magnets from the planes of the balances.

Upon placing the magnets very near to the rim of the balances, a very rapid acceleration took place with both poles, and in every position of the magnets, particularly in the watches Nos. 1 and 2. Upon too near an approach of the magnets, the watch No. 1, and chronometer No. 3, were rendered useless; the former, when the magnets were taken away, gaining no less than about $1\frac{1}{2}$ hour, and the chronometer losing about 50″ in 24 hours; and in again repeating the experiments in the plane of the balances, the rates of the chronometers (without the magnets) were so variable, that it was necessary to determine their rates before and after each application of the magnets; the following, however, is a Table of the results upon the chronometers Nos. 3 and 4.

	No. 2.	No. 4.	
N	+ 0. 2.7	+ 0.43.5	3
S	+ 1.24	+ 0.46	
N	− 5.32	− 1.40	6
S	+ 0.15	− 1.37	
N	+ 5.19	+ 1.18	9
S	− 1.53	+ 1.12	
N	+ 1.59	+ 1.11.7	12
S	+ 2. 7.3	+ 1.29	
N	+ 0.31	+ 1.14	3
S	+ 2. 8	+ 0.43	
N	− 5. 9	− 1.24	6
S	+ 4.25.7	− 0.59	
N	+ 5.25	+ 0.55	9
S	− 1.53	+ 0.42	
N	+ 2.33	+ 1.5	12
S	− 2.33	+ 1.0	

Each of these results in this Table, is the difference of the rates when the magnets were applied, and a mean of the rates of the chronometers before and after the application of the magnets. The rate of the chronometer No. 3, is very different from that given in the former Table; that of No. 4 is nearly the same, and does not appear to have been affected, as No. 3 was, by the close approach of the magnet.

Upon the whole, however, it appears that chronometers will be generally accelerated (particularly if their balances

have not received polarity by the too near approach of any thing magnetical) on ship-board. It appears probable, likewise, that the force of the balance springs is affected in the same way; since it is well known that chronometers having gold balance springs, although more difficult to adjust, yet keep better rates at sea than the others.

However this may be, these observations show the necessity of not trusting to the rates of chronometers ascertained during the time they are on shore; and if the rates are ascertained on board, the chronometers should always be kept in the same place, and also in the same position with respect to the ship; for I have but little doubt that, upon an accurate trial, a chronometer will be found to change its rate, more or less, according as these circumstances are attended to. If these precautions are not taken, land will appear to be considerably to the westward of its true position; this is particularly exemplified in the observations of the Hon. Captain PHIPPS; from which, nearly the whole line of coast on the west side of East Greenland has been placed nearly $1\frac{1}{2}^{\circ}$ too much to the westward, by reason of the acceleration of his chronometers; the same circumstance would have occurred with the chronometers in both of the ships Dorothea and Trent, in the late voyage, had not the longitude been otherwise determined. It is therefore highly requisite that attention should be paid to a circumstance so much connected with the improvement of geography as well as the safety of the seaman.

As an Appendix to these observations, I beg leave to add the following Table of Rates, furnished by Mr. COLEMAN, to which I have prefixed his letter as an introduction.

157, *Leadenhall-Street*,
5th June, 1820.

SIR,

IN compliance with the wish of our common friend Lieutenant EVERARD HOME, I have much pleasure in sending you a table of rates of chronometers. My profession as Teacher of Navigation, conjointly with Mr. NORIE, which connects me so intimately with the Officers of the Honourable East India Company, employed on board the ships trading to India, has enabled me to present you with this table upon an enlarged scale. While engaged in the same service eighteen years, this subject occupied my attention, and it affords me much satisfaction that you are bringing the subject before the Royal Society. My remarks correspond very much with those, I understand, you are now bringing forward.

I am, Sir,

Your obedient servant,

GEORGE COLEMAN.

TABLE

Date.	Persons' Names.	Ships' Names.	Burthen in Tons.	Copper or Iron fastened.	Chronometers.	No. of Days to wind up.	Rates given.
1802 & 1803	Capt. Dunsford	H. C. S. Ceres	1200	Iron	Arnold	1	3.4 gaining
					Margetts	8	5.0 gaining
					Margetts	8	2.5 losing
					Earnshaw	1	6.2 losing
1804 & 1805	Capt. Dunsford	H. C. S. Ceres	1200	Iron	Arnold	1	4.5 gaining
					Margetts	8	5.0 gaining
					Earnshaw	1	6.4 losing
1806 & 1807	Capt. Dunsford	H. C. S. Ceres	1200	Iron	Arnold	1	2.5 gaining
					Arnold	1	4.6 losing
					Margetts	8	5.0 gaining
					Earnshaw	1	1.4 losing
1808 & 1809	Capt. Dodds	H. C. S. Walmer Castle	1260	Iron	Barraud	1	7.3 gaining
					Brockbank	8	4.0 losing
					Arnold	1	3.6 gaining
1810 & 1811	Capt. Mayne	H. C. S. Batavia	750	Iron	Earnshaw	1	6.7 losing
	Mr. Coleman				Arnold	1	3.7 gaining
					Brockbank	2	11.8 losing
					These Chronometers were on shore at Calcutta upwards o		
1812	Capt. Mayne	H. C. S. Batavia	750	Iron	Earnshaw	1	10.5 gaining
	Mr. Coleman				Arnold	1	6.7 gaining
					Brockbank	2	15.4 losing
1813 & 1814	Capt. Blanchard	H. C. S. James Sibbald	700	Iron	The Book containing the various changes of th		
	Capt. Money						
	Mr. Coleman				N. B. The above Chronometers were all un		
	Mr. Decharme						

LE I. A.

To face p. 208.

	Rates found.	Difference of Rates.	REMARKS.
	"	"	
	5.0 gaining	1.6 gained	
	5.2 gaining	0.2 gained	These Chronometers went remarkably steady during the voyage, with the rates found.
	2.0 losing	0.5 gained	
	7.5 losing	1.3 lost	
	6.0 gaining	1.5 gained	These Chronometers gained on board the same as on the preceding voyage.
	5.2 gaining	0.2 gained	
	8.0 losing	1.6 lost	This also *lost* in *similar proportion*
	3.8 gaining	1.3 gained	The same Chronometer as above, same alteration.
	4.0 losing	0.6 gained	
	5.3 gaining	0.3 gained	This Chronometer went five years at 5" on shore, and 5.3 on board.
	1.5 gaining	2.9 gained	The same Chronometer as above, altered after cleaning.
	6.0 gaining	1.3 lost	
	2.8 losing	1.2 gained	
	4.0 gaining	0.4 gained	
	3.2 losing	3.5 gained	This Chronometer went very irregular during the voyage.
	5.4 gaining	1.7 gained	
	13.8 losing	2.0 lost	

vards of three months, and then had the following rates given and found.

18.0 and 23" gaining	.....	NO reliance on this Chronometer at any time.
2.4 gaining	1.7 gained	
18.6 losing	3.2 lost	This Chronometer gradually lost during the whole voyage.

es of these Chronometers is in Captain Blanchard's possession, whose arrival in England is daily expected.

all under my entire charge; I therefore can vouch for the accuracy of the above statements.——G. COLEMAN.

TABL

Date.	Persons' Names.	Ships' Names.	Bur-then in Tons.	Copper or Iron fastened.	Chronometers.	No. of Days to wind up.	Rates given.
1819 & 1820	Capt. Tennent	H. C. S. Apollo	700	Iron	Barraud	1	" 3.0 losing
					Barraud	8	3.5 gaining
					Brockbank & Co.	2	9.5 gaining
1818 & 1819	Capt. S. Lee	H. C. S. Moffatt	720	Iron	Brockbank	1	4.5 losing
					Barraud	2	2.4 gaining
1819 & 1820	Capt. Stewart.	F. T. Sappho	360	Copper	Barraud	8	6.8 losing
					Hatton	8	2.4 gaining
					Parkinson & Co.	1	10.0 gaining
1819	Capt. Pitcher	F. T. Bloxbornbury	720	Copper	Morris	1	2.2 gaining
1818 1819	Capt. Foord	S. S. Phœnix	460	Iron	Brockbank & Co.	2	3.5 losing
1815 & 1816	Capt. Forbes	H. C. S. James Sibbald	700	Iron	Hatton	8	14.0 gaining
					Barraud	1 p.	Going at mean
					Earnshaw	1	15.0 losing
		On the Ship's returning home, the above Chronometers had rates as					
					Hatton	8	14.5 gaining
					Earnshaw	1	19.2 losing
1818 & 1819	Capt. Forbes	H. C. S. James Sibbald	700	Iron	Hatton & Harris	8	9.5 losing
					Hatton & Harris	1 p.	3.0 gaining
					Barraud	1 p.	4.5 losing
		On the homeward bound passage, the same Chronometers					
					Hatton & Harris	8	9.0 losing
					Hatton & Harris	1 p.	5.0 gaining
					Barraud	1 p.	7.0 losing
1819 1820	Capt. Doveton	T. F. Lotus	580	Copper	Barraud	8	6.8 losing

ABLE I. B.

given.	Rates found.	Difference of Rates.	REMARKS.
ing	2.5 losing	0.5 gained	Barraud's Chronometers went steady several months before they altered their rates; but Brockbank's altered its rate in a few weeks.
ining	4.2 gaining	0.7 gained	
ining	12.5 and 16 gaining	6.5 gained	
ing	3.2 losing	1.3 gained	These Chronometers went steady within 2 or 3 tenths, during a voyage of fourteen months.
ining	3.6 gaining	1.2 gained	
ing	5.0 losing	1.8 gained	These went pretty regular with ship rates.
ining	7.0 gaining	4.6 gained	
ining	16.5 and 22 gaining	12.0 gained	This Chronometer proved a very bad one.
ining	3.5 gaining	1.3 gained	
ing	6.3 losing	2.8 lost	This Chronometer went steady at 6.3 till let down.
aining	14.0 gaining	.....	No difference was discovered in the going of this Chronometer outward.
mean time	0.3 gaining	0.3 gained	This Chronometer going well at 0.3, was sold at Calcutta.
ing	18.5 losing	3.5 lost	Altered its rate after leaving Madeira.
rates as under, after being eleven weeks on shore at Calcutta.			
ining	16.0 gaining	1.5 gained	The Chronometers went very steady during the homeward passage with the rates found.
ing	20.7 losing	1.5 lost	
ing	8.5 losing	0.5 gained	These Chronometers were rated at Madeira, and afterwards went steady at those rates.
ining	5.0 gaining	2.0 gained	
ing	6.0 losing	1.5 lost	
nometers had the following rates, after being three months on shore.			
ing	9.0 losing		It therefore appears the Chronometers did *not* vary their rates homeward in the most trifling degree.
ining	5.0 gaining		
ing	7.0 losing		
sing	8.0 losing	1.2 lost	This Chronometer did not alter its rate till at Calcutta.

TABLE

Date.	Persons' Names.	Ships' Names.	Tonnage.	Iron or Copper fastened.	Makers of Chronometers.	No. of Days to wind up.	Box or Pocket.	Rates g
								"
1802 & 1803	Capt. Dunsford	H. C. S. Ceres	1200	Iron	Arnold	1	Pocket	3.4 gaini
					Margetts	8	Box	5.0 gaini
					Ditto	8	—	2.5 losing
					Earnshaw	1	Pocket	6.2 losing
1804 & 1805	Capt. Dunsford	H. C. S. Ceres	1200	Iron	Arnold	1	Pocket	4.5 gaini
					Margetts	8	Box	5.0 gaini
					Earnshaw	1	Pocket	6.4 losin
1806 & 1807	Capt. Dunsford	H. C. S. Ceres	1200	Iron	Arnold	1	Pocket	2.5 gaini
					Ditto	1	—	4.6 losin
					Margetts	8	Box	5.0 gaini
					Earnshaw	1	Pocket	1.4 losin
1808 & 1809	Capt. Dodds	H. C. S. Walmer Castle	1200	Iron	Barraud	1	Pocket	7.3 gaini
					Brockbank	8	Box	4.0 losin
					Arnold	1	Pocket	3.6 gaini
1810 & 1811	Capt Mayne	H. C. S. Batavia	750	Iron	Earnshaw	1	Box	6.7 losin
	Mr. Coleman				Arnold	1	Pocket	3.7 gain
					Brockbank	2	Box	11.8 losin
					The above Chronometers were on shore at Calcutta upwards of			
1812	Capt. Mayne				Earnshaw	1	Box	10.5 gain
					Arnold	1	Pocket	6.7 gain
	Mr. Coleman				Brockbank	2	Box	15.4 losi
1813 & 1814	Capt. Blanchard	H. C. S. James Sibbald	700	Iron	Hatton	8	Box	7.2 gain
					Barraud	2	—	2.4 gain
					Ditto	1	Pocket	3.5 losi
	Capt. Money				Brockbank	1	Box	10.8 losi
	Mr. Coleman				Ditto	1	—	4.4 gain
	Mr. Decharme				Barraud	1	Pocket	2.6 gain
1819 & 1820	Capt. Tennent	H. C. S. Apollo	700	Iron	Barraud	1	Box	3.0 losi
					Barraud	8	—	3.5 gain
					Brockbank	2	—	9.5 gain
1818 & 1819	Capt. S. Lee	H. C. S. Moffatt	720	Iron	Brockbank	1	Box	4.5 losi
					Barraud	2	—	2.4 gain
1815 & 1816	Captain Forbes	H. C. S. James Sibbald	700	Iron	Hatton	8	Box	14.0 ga
					Barraud	1	Pocket	On mea
					Earnshaw	1	Box	15.0 los
					These Chronometers were on shore about eleven wee			
					Hatton	8	Box	14.5 gai
					Earnshaw	1	—	19.2 losi

BLE II. A.

To follow Table I.

Rates given.	Rates found.	Difference of Rates.	REMARKS.
4 gaining	5.0 gaining	1.6 gained	These Chronometers went remarkably well during the voyage, with the rates found.
0 gaining	5.2 gaining	0.2 gained	
5 losing	2.0 losing	0.5 gained	
2 losing	7.5 losing	1.3 lost	
5 gaining	6.0 gaining	1.5 gained	These Chronometers gained during this voyage in the same proportion as in the preceding one.
0 gaining	5.2 gaining	0.2 gained	
4 losing	8.0 losing	1.6 lost	This Chronomerer *lost* in simular proportion.
5 gaining	3.8 gaining	1.3 gained	In the two former voyages there was nearly the same alteration.
6 losing	4.0 losing	0.6 gained	This Chronometer a very excellent one.
0 gaining	5.3 gaining	0.3 gained	This Chronometer went five years & a half at 5″. on shore, and 5″.3 on board.
4 losing	1.5 gaining	2.9 gained	Same Chronometer as mentioned on a former voyage.
3 gaining	6.0 gaining	1.3 lost	These Chronometers went very steady with the rates given them.
.0 losing	2.8 losing	1.2 gained	
.6 gaining	4.0 gaining	0.4 gained	
.7 losing	3.2 losing	3.5 gained	This Chronometer went irregular during the whole voyage.
.7 gaining	5.4 gaining	1.7 gained	
.8 losing	13.8 losing	2.0 lost	
vards of three months, and then had the following rates given and found.			
.5 gaining	18.0 and 23 gaining	.....	No reliance on this Chronometer at any time.
.7 gaining	8.4 gaining	1.7 gained	
.4 losing	18.6 losing	3.2 lost	This Chronometer gradually lost during the whole voyage.
.2 gaining	7.2 gaining	No difference	These Chronometers went remarkably well with the ship, except Capt. Money's box one, which at times veered and hauled exceedingly.
.4 gaining	3.2 gaining	0.8 gained	
.5 losing	2.0 losing	1.5 gained	
.8 losing	12.6 losing	1.8 lost	
.4 gaining	5.8 gaining	1.4 gained	
.6 gaining	2.6 gaining	No difference	
.0 losing	2.5 losing	0.5 gained	These Chronometers went extremely well during the whole voyage.
.5 gaining	4.2 gaining	0.7 gained	
.5 gaining	12.5 then 16 ditto	16.5 gained	This was a very indifferent one throughout.
.5 losing	3.2 losing	1.3 gained	These scarcely varied from the rates found duripg the whole voyage.
2.4 gaining	3.6 gaining	1.2 gained	
14.0 gaining	14.0 gaining	No difference	Chronometer was sold at Calcutta.
In mean time.	0.3 gaining	0.3 gained	
15.0 losing	18.5 losing	3.5 lost	
en weeks, and then the following rates were both given and found.			
4.5 gaining	16.0 gaining	1.5 gained	These went very steady on the passage home with the rates found.
9.2 losing	20.7 losing	1.5 lost	

TABLE I

Date.	Persons' Names.	Ships' Names.	Tonnage.	Iron or Copper fastened.	Makers of Chronometers.	No. of Days to wind up.	Box or Pocket.	Rates give
1818 & 1819	Capt. Forbes	H. C. S. James Sibbald	700	Iron	Hatton	8	Box	9.5 losing
					Ditto	1	Pocket	3.0 gaining
					Barraud	1	—	4.5 losing
					On the Homeward passage the above Chronometers had the follo			
					Hatton	8	Box	9.0 losing
					Ditto	1	Pocket	5.0 gaining
					Barraud	1	—	7.0 losing
1819 & 1820	Capt Stewart	Ship Sappho	360	Copper	Barraud	8	Box	6.8 losing
					Hatton	8	—	2.4 gaining
					Parkinson	1	—	10.0 gaining
1818 1819	Capt. Pitcher	H. C. S. Bloxbornbury	720	Copper	Morris	1	Pocket	2.2 gaining
1818 1819	Capt. Foord	S. S. Phœnix	460	Copper	Brockbank	2	Box	3.5 losing
1819 1820	Capt. Doveton	Lotus	580	Copper	Barraud	8	Box	6.8 losing
1818 & 1819	Capt. W. Morgan	Layton	400	Iron	Barraud	2	Box	6.0 losing
					Ditto - Homeward bound -			7.0 losing
1819 & 1820	Capt. Ogelvie	Juliana	448	Iron	Barraud	1	Box	6.0 losing
					Ditto - Homeward bound -			6.0 losing
1819 1820	Capt. Scott	H. C. S. Charles Grant	1200	Copper	Barraud	8	Box	6.1 losing
1814 1815	Capt. Hope	H. C. S. Surat Castle	1200	Iron	Barraud	8	Box	1.8 gaining
1816 1817	Capt. Hope	H. C. S. Surat Castle	1200	Iron	Same Chronom.	8	Box	5.2 gaining
1813 1814	Capt. Franklin	H. C. S. Northumberland	640	Iron	Barraud	8	Box	0.4 losing
1814 1815	Capt. Cameron	H. C. S. Ann	610	Iron	Barraud	8	Box	2.0 gaining
1816 1817	Capt. B. Laing	H. C. S. Royal Charlotte	1200	Iron	Barraud	8	Box	0.0
1818	Capt. M'Kellar, R. N.	H. M. S. Pique			Barraud	8	Box	6.5 losing
					Next six months on ship its rate was			6.5 losing
1818 & 1819	Capt. Taylor	Cæsar	510	Copper	Barraud	8	Box	2.7 losing
					Next twelve months on shore, its rate was			0.1 ga

LE II. B.

ates given.	Rates found.	Difference of Rates.	REMARKS.
losing gaining losing	8.8 losing 5.0 gaining 6.0 losing	0.5 gained 2.0 gained 1.5 lost	These Chronometers were all rated at Madeira, and went steady at those rates on the passage out.
e following rates given and found, after being on shore three months and upwards.			
losing gaining losing	9.0 losing 5.0 gaining 7.0 losing	No difference.	It therefore appears that these Timekeepers did *not vary* from the rates given them on shore in the smallest degree.
losing gaining gaining	5.0 losing 7.0 gaining 16.5 then 22 gaining	1.8 gained 4.6 gained 12.0 gained	These went regular with the rates found. This very indifferent during the whole voyage.
gaining	3.5 gaining	1.3 gained	
losing	6.3 losing	2.8 lost	This Chronometer went steady at 6.3 till let down.
losing	8.0 losing	1.2 lost	On being landed, it returned to its first rate—6.8 losing.
losing losing	7.2 losing 6.2 losing	1.2 lost 0.8 gained	
losing losing	6.0 losing 5.2 losing	No difference 0.8 gained	
losing	5.4 losing	0.7 gained	
gaining	0.0	1.8 lost	
gaining	5.5 gaining	0.3 gained	
losing	0.0	0.4 gained	
gaining	1.6 gaining	0.4 lost	
	0.4 gaining	0.4 gained	
losing 5 losing	6.2 losing	0.3 gained	This Chronometer returned to the maker's rate on being brought on shore.
losing 0.1 gaining	1.9 losing	0.8 gained	

Date.	Persons' Names.	Ships' Names.	Tonnage.	Iron or Copper fastened.	Makers of Chronometers.	No. of Days to wind up.	Box or Pocket.	Rate
1817	Capt. Sever	West India S. Fanny	384	Iron	Barraud	8	Box	0.5 los
					Ditto	Next four months on shore		
1818	Ditto	Ditto			Ditto			0.2 ga
					Ditto	Next two months on shore		
1819	Ditto	Ditto			Ditto			0.7 ga
1818	Capt. James Kay	H. C. S. Marchioness of Exeter - -	980	Copper	Barraud	8	Box	4.0 los
					Ditto	Next four months on shore		
1817	Capt. R. S. Dalrymple	H. C. S. Vansittart	1240	Copper	Barraud	8	Box	0.6 gai
1818					Ditto	Next six months on shore		
1819	Ditto	Ditto			Ditto	8	Box	0.4 los
1820					Ditto	Since the ship's return to		
1817	Capt. Nairne	H. C. S. General Kyd	1240	Iron	Barraud	2	Box	1.5 ga
&								
1818					Ditto	Next six months on shore		
1816	Capt. R. Drew	West India Ship			Barraud	2	Box	9.3 ga
1817					Ditto	Next five months on shore		
1817	Ditto	Ditto			Ditto			8.4 ga
1818					Ditto	Next three months on sho		
1818	Ditto	Ditto			Ditto			4.5 ga
1819					Ditto	Next thirty-two days on s		
1819	Capt. Cookesley	Ship Malida	480	Copper	Barraud	2	Box	6.5 los
					Ditto	Next forty days on shore.		
1818								
&	Capt. Johnson	H. C. S. Camden	490	Iron	Barraud	2	Box	Going r
1819								
1816	Capt. Barwick				Barraud	2	Box	0.0 to
					On shore this Chronometer still increased to 11.5 ga			
1816	Capt. Tremenhere	H. C. S. Asia	890	Iron	Barraud	8	Box	2.0 ga
&								
1817					Ditto	Next six months on shore		
1817	Capt. Auber	E. I. S. Lady Raffles	610	Iron	Barraud	2	Box	5.0 ga
1816	Capt. Druce				Barraud	1	Pocket	2.5 los
1815	Capt. Mortlock	H. C. S. Lowther Castle	1200	Copper	Barraud	1	Pocket	1.8 los
1819	Capt. Gribble	H. C. S. Princess Charlotte of Wales -	978	Iron	Barraud	8	Box	11.0 los
&						6	Box	2.0 ga
1820								

BLE II. C.

Rates given.	Rates found.	Difference of Rates.	REMARKS.
"	"	"	
0.5 losing	0.9 gaining	1.4 gained	
n shore.....	2.0 gaining		
0.2 gaining	1.4 gaining	0.6 lost	
n shore	0.7 gaining		
0.7 gaining	1.4 gaining	0.7 gained	In this instance it returned to the same rate as on the *preceding* voyage.
4.0 losing	4.1 losing	0.1 lost	
n shore.....	3.3 losing		
0.6 gaining	0.2 gaining	0.4 lost	
n shore	0.7 losing		It therefore appears this Chronometer varied precisely the same quantity and the same way, two succeeding voyages: this ship, it may be necessary to remark, is copper fastened throughout.
0.4 losing	0.8 losing	0.4 lost	
urn to England..	0.2 gaining		
1.5 gaining	1.7 gaining	0.2 gained	
n shore	3.0 gaining		
9.3 gaining	10.3 gaining	1.0 gained	
n shore	8.4 gaining		
8.4 gaining	8.9 gaining	0.5 gained	
on shore	8.0 gaining	and then gradually decreased to 4.5, the rate when taken on board.	
4.5 gaining	6.5 gaining	2.0 gained	
ys on shore	5.0 gaining	and was then cleaned.	
6.5 losing	6.5 losing	No difference	This Chronometer, since its return on board ship, has taken up again the rate of 6.5, which favours Mr. Fisher.
shore.....	8.0 losing		
Going mean time	9.3 gaining	9.3 gained	This increase of rate took place very gradually during the first four months, after which it kept that rate, making an error of *only* 16", the following fifteen *months*, and continued the *same rate* for five months following on *shore*; was then cleaned.
0.0 to	9.5 gaining	in the course of thirteen months at sea, and the following two months.	
11.5 gaining	12.2 gaining	0.7 gained	And went at 12.2, gaining next three months on shore.
2.0 gaining	2.3 gaining	0.3 gained	
n shore	3.7 gaining	and was then cleaned.	
5.0 gaining	7.8 gaining	2.8 gained	And went next four months on shore at 5.5 gaining
2.5 losing	3.4 losing	0 9 lost	And went next eleven months on shore at 0.3 losing.
1.8 losing	1.7 losing	0.1 gained	And went next forty days on shore at 2.1 losing; then cleaned.
11.0 losing	12.2 losing	1.2 lost	Since the ship's arrival it has been going at 14.8 losing.
2.0 gaining	2.3 gaining	0.3 gained	..... 1.9 gaining.

Date.	Present Name.	Ship's Name.	Tons.	Iron or Copper Fastened.	Makers of Engines.
1817	Capt. Scott	Wm Hadlin S. Percy	351	Iron	Barnard
1818	Do	Do			Do
					Do
1819	Do	Do			Do
1818	Capt. James Day	H. C. S. Manchioness of Exeter	990	Copper	Barnard
1817	Capt. R. S. Dalrymple	H. C. S. Vansittart	1200	Copper	Barnard
1818					Do
1819	Do	Do			Do
1820					Do
1817 & 1818	Capt. Watts	H. C. S. General Kyd	1210	Iron	Rennie
					Do
1816	Capt. E. Drew	Wm Hadlin Ship			Barnard
1817					Do
1817	Do	Do			Do
1818					Do
1818	Do	Do			Do
1819					Do
1819	Capt. Cockerly	Ship Matilda	460	Copper	Barnard
					Do
1818 & 1819	Capt. Johnson	H. C. S. Camden	490	Iron	Barnard
1819	Capt. Barrick				Barnard
1818 & 1817	Capt. Tremenhere	H. C. S. Asia	800	Iron	Barnard
					Do
1817	Capt. Archer	H. C. S. Lady Hadlin	610	Iron	Barnard
1818	Capt. Dyson				Barnard
1818 1819	Capt. Murdock	H. C. S. Earl of Balcarres	1200	Copper	Barnard
1818 & 1820	Capt. Gibbin	H. C. S. Princess Charlotte of Wales	978	Iron	Barnard

XVI. *An account of a new mode of performing the High Operation for the Stone.* By Sir EVERARD HOME, *Bart. V. P. R. S.*

Read June 15th, 1820.

HAVING performed the high operation for the stone in a manner less severe and less dangerous to the patient than that now in use, and by which the stone is more easily extracted, I am desirous of having it put upon record in the Philosophical Transactions, that at the same time it is made public, my claim to the first adoption of this mode may be established, which could not be so well done, were I to postpone the present communication.

For the previous information that led me to adopt this method, I beg to refer to the History of the High Operation for the Stone, published by Mr. CARPUE, to which publication I am indebted for the principle, and only claim the merit of having made, what must be allowed to be, a considerable improvement.

Case, and Operation.

JOHN RIVINGTON, aged 16, who had suffered as long as he could remember from pain in the act of making water, and immediately after the whole quantity was evacuated, came into St. George's Hospital on the 19th of May, 1820. His complaint was found to be the stone, and I performed the operation on the 26th of the same month, in the following manner.

The boy was laid with his back upon a table, his feet supported on a chair. An incision was made in the direction of the linea alba between the pyramidales muscles, beginning at the pubes, and extending upwards four inches in length: it was continued down to the tendon. The linea alba was then pierced close to the pubes, and divided by a probe-pointed bistory to the extent of three inches. The pyramidales muscles had a portion of their origin at the symphisis pubis detached to make room. When the finger was passed down under the linea alba, the fundus of the bladder was felt covered with loose fatty cellular membrane. A silver catheter, open at the end, was now passed into the bladder by the urethra, and when the point was felt by the finger in the wound pressing up the fundus, a stilet that had been concealed was forced through the coats of the bladder, and followed by the end of the catheter. The stilet was then withdrawn, and the opening through the fundus of the bladder enlarged toward the pubes by a probe-pointed bistory sufficiently to admit two fingers, and then the catheter was withdrawn. The fundus of the bladder was held up by one finger, and the stone examined by the fore-finger of the right hand. A pair of forceps with a net attached was passed down into the bladder, and the stone directed into it by the finger: the surface being very rough, the stone stuck upon the opening of the forceps, and being retained there by the finger, was extracted. A slip of linen had one end introduced into the bladder, and the other was left hanging out of the wound, the edges of which were brought together by adhesive plaster. A flexible gum catheter, without the stilet, was passed into the bladder by the urethra, and kept there

by an elastic retainer surrounding the penis. The patient was put to bed and laid upon his side, in which position the urine escaped freely through the catheter.

The calculus was of the roughest mulberry kind, was nearly spherical, and weighed one ounce. As no blood had been lost in the operation, twelve ounces were taken from the arm. Outlines of the different instruments are annexed. Pl. XXIV.

May 27. The patient had rather a restless night, but had some sleep; the wound very tender: all the urine escaped by the catheter; no tenderness on the abdomen. The slip of linen was withdrawn, which gave great relief. The author begs to remark, that leaving any such slip in the bladder is unnecessary, as no urine escaped through the upper wound; it need only be left in the external wound, to prevent the formation of abscess.

May 28. The patient had some quiet sleep in the night; pulse quick, bowels open, the wound less tender; the urine escapes freely. Had his bed completely changed: in the evening the catheter was plugged up, and till cleared, the urine came by the wound. The pulse was quick and full, the tongue white. He lost ten ounces of blood, which upon standing became cupped and buffy.

May 29. The wound still tender. Had not much sleep in the night. The catheter being again plugged up, it was altogether withdrawn, none being at hand of a proper size to replace it; and the time for the urine to diffuse itself being past.

The catheter had been made to retain its curve; to do which its inside had less varnish, so that when soaked in

urine it became spongy, and was readily clogged. The catheters used in this operation should have the inside of the tube polished like the outside.

May 30. The patient had a good night. The urine escaped by the wound, which looked healthy; he is quite free from pain, and in all respects better. A little urine came by the penis. He was moved into another bed.

May 31. His night not so good, but the pulse natural; the tongue losing its whiteness; the urine came for the most part by the wound, but in gushes of two or three table-spoonfuls at a time. Sat up for ten minutes in a chair.

June 1. He sat up an hour. Urine still comes principally by the wound.

June 2. The patient is gradually gaining strength; sat up twice in the day.

June 3. He sat up in a chair for upwards of two hours; and while in the effort of having a stool, a considerable quantity of urine came by the urethra.

June 4. Some urine still came by the wound; the abdominal muscles not acting, excepting when at stool. After sitting up some hours a soft bougie was passed, and immediately withdrawn, to clear the urethra: it was followed by a few drops of urine.

June 5. Sat up nine hours; and twice in a full stream made eight ounces of water; from that time none escaped by the wound.

June 9. The wound has become superficial, and the bladder retains eight or ten ounces at a time.

It is to be remarked, that the stone had been an unusual number of years in the bladder, was of the roughest possible

Fig. 1.

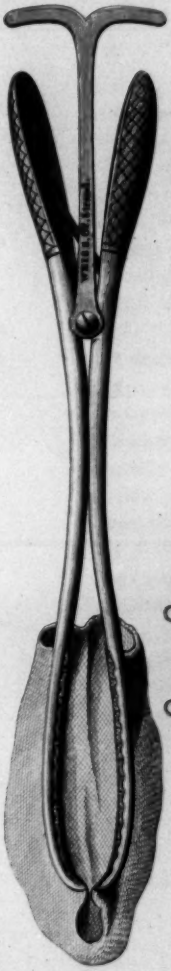


Fig. 3.

Fig. 4.

Fig. 5.

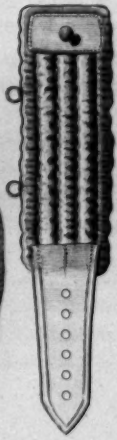
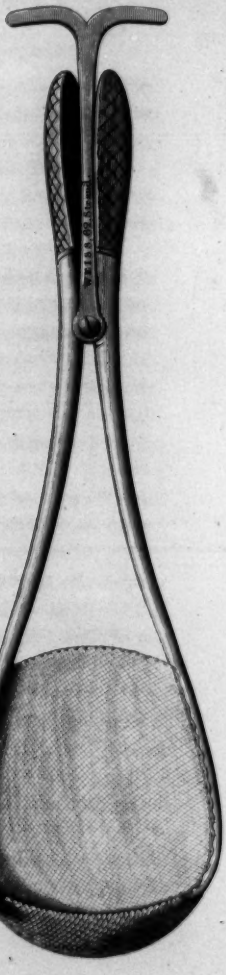


Fig. 2.



kind, and yet so mild were the effects of the operation, that in ten days the bladder completely recovered its healthy actions.

EXPLANATION OF PLATE XXIV.

This Plate contains five figures $\frac{3}{5}$rds of their real size.

Fig. 1. The forceps closed by means of a spring, in which state they are to be introduced into the bladder; the silk net-bag in a collapsed state.

Fig. 2. The forceps opened by pressing the spring handles, and the silk net-bag extended to receive the stone, upon which the forceps are allowed to close, by removing the pressure from these handles. The stone by falling to the bottom of the bag, becomes lower than the bent point of the forceps, and does not require an opening larger than itself to admit of being extracted. The stone is to be pulled out by the upright handle.

Fig. 3. The representation of a portion of the penis with the catheter in the urethra, which is prevented from coming out by the retainer applied round the penis.

Fig. 4. The flexible gum catheter of the proper length to reach the lower posterior part of the bladder.

Fig. 5. The catheter retainer detached from the penis.

XVII. *A Sketch of an Analysis and Notation applicable to the estimation of the value of Life Contingencies.* By BENJAMIN GOMPERTZ, *Esq. F. R. S.*

Read June 29, 1820.

THE estimation of the value of property, connected with life contingencies, has for many years occupied the attention of the philosophers, as well as the monied and landed interest of this country. The many institutions now existing in England, for the purpose of granting annuities and assurances on lives, are a sufficient evidence that they are conceived to yield advantages to the community:—advantages which seem to present themselves in two points of view; the one, the gain accruing to the parties granting the assurance or other object; the other, the benefit to be received by persons purchasing those grants. In a political point of view, it appears a question of great importance to decide, what ought to be the demands of those companies, so that the public may reap the greatest benefit from them? And the only means of answering this question, is the possession of the mathematical and philosophical principles, by which those institutions ought to be guided. In the present improved state of the science of life assurances, it is not sufficient for a proper regulation to follow old customs, and calculations, drawn from a less perfect experience than we have now the means of obtaining; but every company, to reap the advantage of the progressive state of the science, should not only possess

every knowledge relative to this science, which it may be within its immediate power to acquire, but it should promulgate its individual information; that the actuaries of the different societies may, by their mathematical skill, collect for the common good of all, from multiplied resources, that which they cannot obtain from a less general observation. I am induced to venture this hint, as it is my firm belief, that the tables generally adopted, might, by this means, receive many extremely necessary corrections; for those tables should be as accurate as they can possibly be made, and the interest should be calculated at that rate which shall appear to be the average interest to be made for money; but such additional demands should be made by the company or institution, as to leave an adequate portion for its security, profit, and expenses; for it does not seem possible, in the various beneficial applications which can be made from a proper knowledge of this branch of the mathematics, to judge universally how to adopt tables of mortality, which are not correct in themselves, connected with a rate of interest which is not the average rate made in reality, so that the advantage may tend to any one direction. In granting assurances on lives, it is a practice to use a certain table of mortality, and to calculate at a certain rate of interest, without making any additional charge; in the presumption, that the tables are in themselves incorrect, but that their deviation from the truth, is in favour of the society; and that the interest of money is less than that which they can really make: but such a plan does not appear to me sufficiently scientific, to be followed by companies concerned with life contingencies generally. It is not my intention in the paper I have at present the honour

to present to this profoundly learned Society, to offer my opinion on the rates of mortality; but my object is to propose a plan of analysis and notation, which I conceive may be applied with utility to most problems likely to occur, and capable of suggesting a variety of new speculations in the pursuit of this science. Many accurate and ingenious men have occupied their hours in the improvement of this subject. Messrs. MORGAN, BAILY, and MILNE, of the present age, are among the number of mathematicians to whom this department is greatly indebted; the works of the former two gentlemen have been long before the public; that of Mr. MILNE, was not earlier than about the commencement of this year in my possession; but I felt much gratified with the able manner in which he has treated his different subjects; and particularly pleased with his notation, in his sixth chapter, referring to the different orders of survivorship.

I feel thankful for the information I have received from the labours of those who have preceded me; and I hope that this sketch may be received as a wish to aid science, but not as a medium to censure those whose steps may sometimes have faltered in the paths to knowledge. To a true philosopher, it will ever be much more pleasing to grant even more praise than is actually due, than to pluck the laurel from the deserving brow. This is an observation which might frequently be addressed to authors, but I profess no particular point of application in my remark.

BENJAMIN GOMPERTZ.

14th June, 1820.

Section I. Art. I. A function, that is an expression made up of certain quantities, has been often very usefully expressed by some letter with those quantities written underneath, of which that function or expression is made up. And frequently those quantities only are placed under, which it may be the particular object to bring into notice; thus, if in an analysis we had the frequent occurrence of some particular expression, $\sqrt{a^2+x^2+\sqrt{x+y}}$, for instance, it might be convenient to put some letter to represent it; and if we had two or more expressions of the same form made up of different letters, such for instance as $\sqrt{a^2+x^2+\sqrt{x+y}}$, and $\sqrt{a^2+z^2+\sqrt{z+w}}$, it may be more convenient to express them by some generic character, which shall still involve the peculiarity of each; thus, by writing for the one $M_{x,y}$, and for the other $M_{z,w}$, and this or a similar mode of notation; becomes more necessary when we are ignorant of the form of the expressions to which our analysis is to be applied.

Art. 2. If for x in the expression M_x signifying some function of x, we write separately $x=n$, $x=n+p$, $x=n+2p$, $x=n+3p$, &c. x increasing by the continual addition of p; then the sum of the terms commencing with $x=n$ and finishing with $x=m$, is $M_n+M_{n+p}+M_{n+2p}$ &c. $\ldots M_m$; and to express this operation on x, I use the symbol $\left.\begin{matrix}x\\p\\n\\m\end{matrix}\right|$ prefixed to the function of x; that is, I should write $\left.\begin{matrix}x\\p\\n\\m\end{matrix}\right| M_x$ for this sum. This is the same as what is called the finite integral of

M_{x+p}; from $x=n$ to $x=m$; that is, the first value of the increment M_{x+p} of the series being M_{n+p}, and the last M_{m+p}, or which is the same thing, the first term of the series being M_n and the last term of the series M_m. And thus would $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right| M_{x+z}$ express $M_{n+z}+M_{n+1+p}+M_{n+1+2p}\ldots\ldots M_{m+z}$, and also would $\left|\begin{smallmatrix} p \\ n+z \\ m+z \end{smallmatrix}\right| M_x = M_{n+z}+M_{n+1+p}+M_{n+1+2p}\ldots\ldots M_{m+z}$, as is evident by writing $n+z$ and $m+z$ respectively in the room of n and m in the first of the series mentioned; consequently, $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right|^{x} M_{1+z} = \left|\begin{smallmatrix} p \\ n+z \\ m+z \end{smallmatrix}\right|^{x} M_x$; they both being expressive of the sum of the same series. Moreover, because when x becomes n, $x+z$ becomes $n+z$, and when x becomes m, $x+z$ becomes $m+z$; therefore the symbols $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right|^{x}$ and $\left|\begin{smallmatrix} p \\ n+z \\ m+z \end{smallmatrix}\right|^{x+z}$ when prefixed to the same function mean the same thing, that is $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right|^{x} M_x = \left|\begin{smallmatrix} p \\ n+z \\ m+z \end{smallmatrix}\right|^{x+z} M_x$.

Also because $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right|^{x} M_{p+x}$ is the symbol for $M_{n+p}+M_{n+2p}$ $+$ &c. $\ldots\ldots M_{m+p}$, and $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right|^{x} M_x$ is the symbol for M_n+M_{n+p} $+_{n+2p}+$ &c. $\ldots\ldots M_m$, therefore $\left|\begin{smallmatrix} p \\ n \\ m \end{smallmatrix}\right|^{x} M_x = M_n - M_{m+p}+$

$\left.\begin{matrix} x \\ p \\ n \\ m \end{matrix}\right| M_{p+x}$, and also $= M_n + \left.\begin{matrix} n \\ p \\ m \to p \end{matrix}\right| M_{p+n}$, or $= \left.\begin{matrix} x \\ p \\ n \to p \\ m \to p \end{matrix}\right| M_{p+x}$. This last is also evident from above.

Art. 3. It may be proper to state that the symbol $\left.\begin{matrix} \\ \\ \\ \end{matrix}\right|$ is not necessarily written with the letters x, p, n, m; but that with other letters it will, *mutatis mutandis*, have a similar meaning: the first or highest letter within the symbol expressing the constant increment of the variable quantity above the symbol; the second, the value of that variable quantity at the commencement; and the last or lowest letter the value thereof at the end. If this letter be infinite, we omit its notation and write the symbol thus $\left.\begin{matrix} x \\ p \\ n \end{matrix}\right|$. If p, or the first letter within be infinitely small, or o comparatively with finites, then the symbol will stand $\left.\begin{matrix} n \\ o \\ n \\ m \end{matrix}\right|$ and will express the integral of a differential expression of x between the limits n and m of x, and will be the same as the fluent of a fluxional expression between the same limits, *mutatis mutandis*.

Art. 4. L_a, L_b, L_c, &c. are put to denote the number of persons living at the ages a, b, c, &c. in a given table of mortality, and $L_{a,\,b,\,c,\,\&c.}$ is put for an abbreviation of $L_a \times L_b \times L_c$, &c. also $L_{x:\,a,\,b,\,c,\,\&c.}$ is put for an abbreviation of $L_{a+x} \times L_{b+x} \times L_{c+x}$; $L_{(x:\,a,\,b,\,c,\,\&c.)\,d,\,e,\,f,\,\&c.}$ for an abbreviation of $L_{a+x} \times L_{b+x} \times L_{c+x}$ &c. $\times L_d \times L_e \times L_f$ &c.

Hence the chances of nominated persons of the ages a, b, c, &c. living respectively, the times x, y, z, &c. are $\frac{L_{a+x}}{L_a}$, $\frac{L_{b+y}}{L_b}$,

$\frac{L_{c+z}}{L_c}$ &c. considered independently of each other; and the chance that the event shall take place conjointly, that is, that every one of all the events shall take place is $\frac{L_{a+x}}{L_a} \times \frac{L_{b+y}}{L_b} \times \frac{L_{c+z}}{L_c}$ &c. or $\frac{L_{a+y,\, b+y,\, c+z,\, \&c.}}{L_{a,\, b,\, c,\, \&c.}}$; and if y, z, &c. are each equal to x, the expression may be further abbreviated thus, $\frac{L_{x:\, a,\, b,\, c,\, \&c.}}{L_{a,\, b,\, c,\, \&c.}}$. Note, that one year is considered the unite of time.

And if r be the present worth of one pound due in one year certain, $r^x \cdot \frac{L_{x:\, a,\, b,\, c,\, \&c.}}{L_{a,\, b,\, c,\, \&c.}}$ will be the present worth of one pound to be received in the time x in case nominated persons of the ages a, b, c, d, &c. should be all living at that time.

Corollary. Hence, $\overbrace{\left.\begin{matrix} p \\ n \\ m \end{matrix}\right|}^{x} r^x \cdot \frac{L_{x:\, a,\, b,\, c,\, \&c.}}{L_{n:\, a,\, b,\, c,\, \&c.}}$ will denote the present value of a periodic income of one pound, payable at equal intervals p of time, the first payment being to be made in the time n, and the last in the time m, on the contingency of the persons whose present ages are a, b, c, &c. being jointly living at those intervals; interest being reckoned at the rate per cent. which makes the present value of one pound certain due in one year equal to r; and if there be no danger of mistaking the variable radical, we omit it in the prefixed symbol, and would write the last expression $\overbrace{\left.\begin{matrix} p \\ n \\ m \end{matrix}\right|}^{x} r^x \cdot \frac{L_{x:\, a,\, b,\, c,\, \&c.}}{L_{n:\, a,\, b,\, c,\, \&c.}}$ and this we would write still shorter when a more developed expression is not necessary, thus $\overbrace{\left.\begin{matrix} p \\ n \\ m \end{matrix}\right|}^{r} a, b, c$, &c. to signify as

before. The present value of a periodic income of one pound payable on the joint lives of persons of the present ages a, b, c, &c. at equally distant intervals p, the first payment being due in the time n, and the last in the time m, the present value of one pound certain due in one year being r.

If there be not any character in the place of the r, in the last symbolic form, the interest is supposed to be the same as in some previous consideration, which shall be evident from the text; thus, if we had been conversing of an interest of 5 per cent. per annum, we should write $\overset{1}{\underset{1}{\big|}}\overline{a, b, c,}$ to express the present value of an annuity of one pound (that is one pound payable yearly) on the joint lives of the present ages a, b, &c. the first payment to be made in one year, because in this case $p=1$, $n=1$, and m is infinite, or extends to the longest possible duration of life.

Art. 5. If the income is on the present ages a, b, c, &c. between the terms &c., on the contingency of r or more of them being living, we write as a symbol of its present value $\overset{r}{\underset{m}{\overset{p}{\underset{n}{\big|}}}}\overline{a, b, c, \&c.}$, and according to this notation we should have in the following particular cases for the present value of the income $\overset{r}{\underset{m}{\overset{p}{\underset{n}{\big|}}}}\overline{a, b, c}$ the same as $\overset{r}{\underset{m}{\overset{p}{\underset{n}{\big|}}}}\overline{a, b, c,}$; $\overset{r}{\underset{m}{\overset{p}{\underset{n}{\big|}}}}\overline{a, b, c}$ for the term depends on two or more of the three persons whose present ages are a, b, c, being living; $\overset{r}{\underset{m}{\overset{p}{\underset{n}{\big|}}}}\overline{a, b, c}$, when it depends on one or more of the three being living; that is, what is termed on the longest of the lives; and $\overset{r}{\underset{m}{\overset{p}{\underset{n}{\big|}}}}\overline{a, b, c}$,

when it depends on none, or any of them being living, and is therefore the income certain and quite independent of the ages *a*, *b*, *c*, and therefore this case may be written without those letters, thus $\overset{r}{\underset{m}{\overset{p}{s}}}\Big|\overset{}{\underset{o}{}}$, and will be expressive of the present value of an income certain for the term, &c.; *o* inserted in the angle signifying that it does not involve any contingency; and this presents us with a ready notation for the purpose of expressing an income for a term, a rate of interest, and a periodic interval of payment given on any nominated contingency specified by any particular character, by placing that character in the angular point; thus if the contingency involved were designated by the character C, then the income for the term, rate of interest, &c. depending on that contingency, we should denote by $\overset{r}{\underset{m}{\overset{p}{s}}}\Big|\overset{}{\underset{C}{}}$

Art. 6. Moreover, as $\overset{r}{\underset{m}{\overset{p}{s}}}\Big|\overset{}{\underset{o}{}}$ expresses the value of the income certain for the term, and $\overset{r}{\underset{m}{\overset{p}{s}}}\Big|\overset{}{\underset{a,b,c,\&c.}{}}$ expresses the value of the income for the term on the contingency of ν or more of the persons of the present ages *a*, *b*, *c*, &c. being living; the excess of the former above the latter, will express the value of the income for the term on the contingency of $\mu-\nu+1$, or more of the persons being dead; if μ be the number of persons in all: "because it is certain that out of μ persons living at any "time, there will after that time either be ν or more of them "living, or $\nu-1$ or less of them living including *o*; but $\nu-1$ "or less of them being living, is the same as $\mu-\nu+1$ or more

Fig. 1.

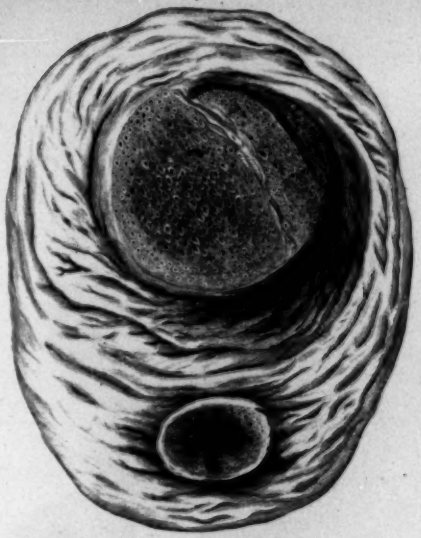
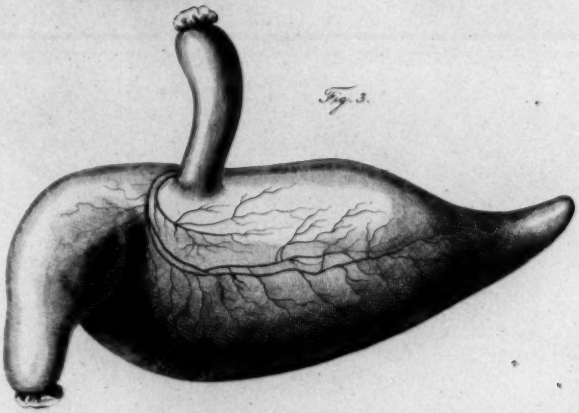


Fig. 2.

Fig. 3.



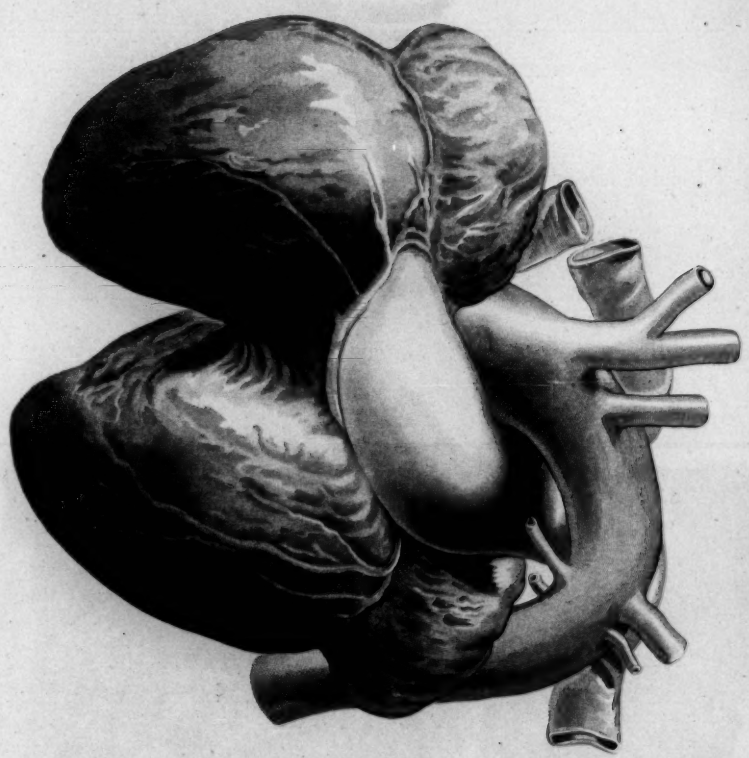


Fig. 1.

Fig. 2.

Fig. 1.

Fig. 2.

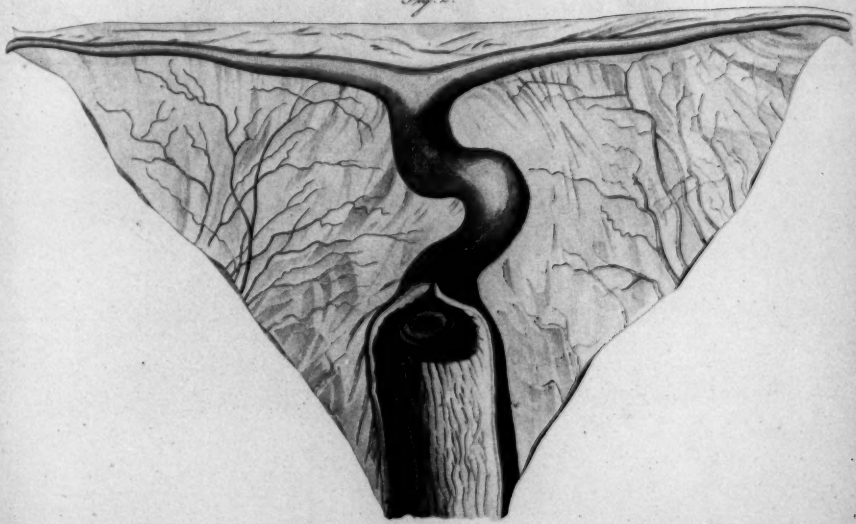


Fig. 1.

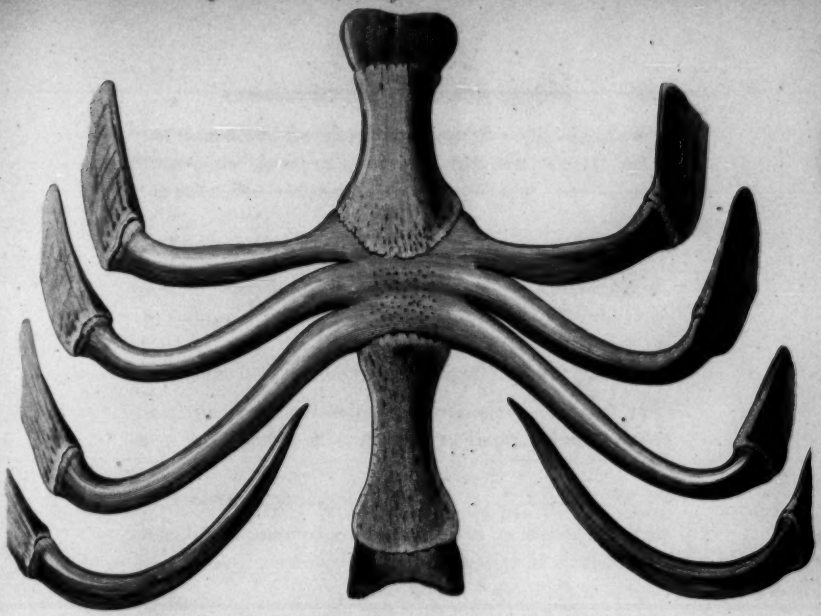
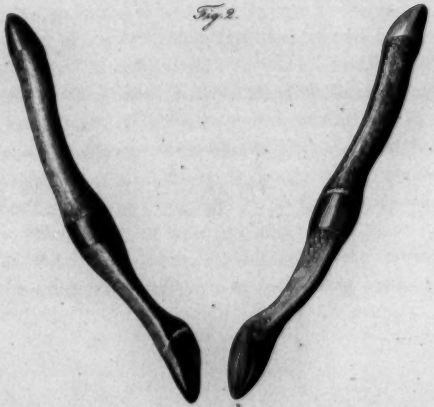


Fig. 2.



" of them dead; therefore the chance of ν of them being liv-
" ing $+$ the chance of $\mu \rightarrow +1$ of them being dead, is equal
" to unity, that is certainty," and the said excess will be writ-
ten $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} \frac{\quad}{0} \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} \frac{a, b, c, \&c.}{\nu}$, and is expressive of the chance of π
or more being dead, π being equal to $\mu - \nu + 1$; or μ, that is,
the number of persons in all being $= \pi + \nu - 1$; and as the sign
$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}$ of summation and the interest indicated by r, the present va-
lue of one pound certain to be received at the years end, affect
both contingencies alike, we may join those contingencies and
use but one symbol, and we shall have $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} \frac{-, a, b, c, \&c.}{0, \nu}$ for the
value of the income for the term on the contingency, that out
of $\pi + \nu - 1$ persons, there shall be π or more of them dead.
Accordingly would $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} \frac{-, a, b, c,}{0, 3}$, $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} \frac{-, a, b, c,}{0, 2}$, and $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} \frac{-, a, b, c}{0, 1}$ re-
spectively signify the value of the income for the term on the
contingency of one or more being dead, of two or three be-
ing dead, or of all being dead. And these besides being an
appropriate abbreviation of the expressions, likewise indicate,
that if from the value of the income certain for the term we
subtract separately the value for the income for the term on
the contingency of all three being living, on the contingency
of two or more being living, and on the contingency of one
or more being living, of three persons, we shall have respec-
tively the value of the income for the term on the contingency
of one or more being dead, two or more being dead, or of all

being dead of three persons. Again $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c.}{\nu - \varrho} - \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c.}{\nu}$, or, abbreviated, $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c. - a, b, c, \&c.}{\nu - \varrho \quad \nu}$ would express the value for the term of the income on the contingency of there not being more living than $\nu - 1$, and not less living than $\nu - \varrho$; and taking $\varrho = 1$, we have $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c. - a, b, c, \&c.}{\nu - 1 \quad \nu}$, the value on the contingency of there being precisely $\nu - 1$ of them living; and if there are μ lives in all, the same symbol will also express the value on the contingency of there being precisely $\mu - \nu + 1$ dead.

Art. 7. If the income for the term depended on ν, or more nominated persons of the present age a, b, c, &c. being living, on ν' or more of the present ages a', b', c', &c. on ν'' or more of the persons of the present ages a'', b'', c'', &c. being living, we should express its present value, thus

$$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c. : a', b', c', \&c. \; a'', b'', c'', \&c.}{\nu \quad \nu' \quad \nu'', \&c.}$$

If the income for the term depended on some contingency designated by C, provided there were ν or more living of the persons of the present ages a, b, c, &c. we should designate it thus $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{: a, b, c, \&c.}{c, \nu}$. And therefore, if there were μ persons of the ages a, b, c, &c. in conformity with our plan, we should denote by $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{- : a, b, c, \&c.}{C \quad \nu}$, the present value of the income on the contingency C, proved $\mu - \nu + 1$, or more of the persons of the present ages, a, b, c, &c. were dead.

Art. 8. If one pound is to be received at the expiration of the first of the equal periods p, after the expiration of the time $n-p$, which shall happen after the failure of any of the above conditions of joint or single existence of the persons in question, provided that that failure should take place between the intervals $n-p$ and m; the present value of this sum will be the present value discounted for the period p of the income on the contingency of the conditions not failing, the first payment to be made at the period $n-p$, and the last at the period $m-p$, less the present value of the income on the contingency of the conditions not failing, the first payment to be made in the time n, and the last in the time m. Thus suppose the income, payable at every interval p, of one pound on the contingency of certain lives remaining, the first payment to be made at the time n, and the last at the time m, be represented by $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\!\!\!

in the same manner $\left|\begin{smallmatrix}r\\ p\\ \pi-p\\ \pi-p\end{smallmatrix}\right|_{C} \times r^{\pi-p}$ is the chance of its not having failed on or before the time $\pi-p$; and the excess of the latter above the former, is the chance of its failing between the intervals $\pi-p$ and π, which multiplied by r^{π} gives $\left|\begin{smallmatrix}r\\ p\\ \pi-p\\ \pi-p\end{smallmatrix}\right|_{C} \times r^{p} - \left|\begin{smallmatrix}r\\ p\\ \pi\\ \pi\end{smallmatrix}\right|_{C}$, for the present value of one pound, to be received at the expiration of the time π, in case the condition should fail between the time $\pi-p$ and π; and if π be successively interpreted by $n, n+p$; $n+2p$, &c. m, the sum of the resulting expressions, will be the value of one pound to be received at the first of the periods p from the time $n-p$ that shall happen after the failure of the condition, provided that that failure takes place between the periods $n-p$ and m; but because $\left|\begin{smallmatrix}r\\ p\\ n\\ m\end{smallmatrix}\right|_{C} = \left|\begin{smallmatrix}r\\ p\\ n\\ m\end{smallmatrix}\right|_{C} + \left|\begin{smallmatrix}r\\ p\\ n+p\\ m+p\end{smallmatrix}\right|_{C} + \left|\begin{smallmatrix}r\\ p\\ n+2p\\ n+3p\end{smallmatrix}\right|_{C}$ + &c. .... $\left|\begin{smallmatrix}r\\ p\\ m\\ m\end{smallmatrix}\right|_{C}$, and similarly $\left|\begin{smallmatrix}r\\ p\\ n-p\\ m-p\end{smallmatrix}\right|_{C} = \left|\begin{smallmatrix}r\\ p\\ n-p\\ n-p\end{smallmatrix}\right|_{C} + \left|\begin{smallmatrix}r\\ p\\ n\\ n\end{smallmatrix}\right|_{C} + \left|\begin{smallmatrix}r\\ p\\ n+p\\ n+p\end{smallmatrix}\right|_{C}$ + &c. .... $\left|\begin{smallmatrix}r\\ p\\ m-p\\ m-p\end{smallmatrix}\right|_{C}$; therefore the said value is equal to $\left|\begin{smallmatrix}r\\ p\\ n-p\\ m-p\end{smallmatrix}\right|_{C} \times r^{p} - \left|\begin{smallmatrix}r\\ p\\ n\\ m\end{smallmatrix}\right|_{C}$ as above asserted.

From the two equations first cited, it appears that $\left|\begin{smallmatrix}r\\ p\\ n-p\\ m-p\end{smallmatrix}\right|_{C} = \left|\begin{smallmatrix}r\\ p\\ n\\ m\end{smallmatrix}\right|_{C} + \left|\begin{smallmatrix}r\\ p\\ n-p\\ n-p\end{smallmatrix}\right|_{C} - \left|\begin{smallmatrix}r\\ p\\ m\\ m\end{smallmatrix}\right|$; the value of the above contingency

therefore becomes $(r^p - 1) \cdot \overset{r}{\underset{n}{\overset{p}{|}}}\frac{}{C} + \left\{ \overset{r^2}{\underset{n-p}{\overset{p}{|}}}\frac{}{C} - \overset{r}{\underset{m}{\overset{p}{|}}}\frac{}{C} \right\} \cdot r^p$.

If we look to the expression $\overset{r}{\underset{m-p}{\overset{p}{|}}}\frac{}{C} \times r^p - \overset{r}{\underset{m}{\overset{p}{|}}}\frac{}{C}$, we shall discover that if the increment of some variable quantity x be equal to p, and that be the only variable quantity concerned in the functions $\overset{r}{\underset{m-x}{\overset{p}{|}}}\frac{}{C} \times r^x$, that our quantity, the value of the assurance, will the increment thereof after x be made equal to o, and the assurance, or the increment of $\overset{r}{\underset{m-x}{\overset{p}{|}}}\frac{}{C} \times r^x$, thus modified, I shall denote by $\overset{r}{\underset{m}{\overset{p}{|}}}\frac{}{C}$. And in conformity with this notation, I should write $\overset{r}{\underset{m}{\overset{p}{|}}}\frac{}{a, b, c}$, &c. for the assurance of one pound to be received at the first of the equal periods p from the time $n-p$ which shall happen after the time $n-p$, and not after the expiration of the time m; after the extinction of the joint lives of the persons now aged a, b, c, &c. also by $\overset{p}{\underset{m}{|}}\frac{}{a, b, c, \&c.}$. I should denote the present value of the assurance on similar conditions with respect to the failure of the last r survivors, &c. When m is infinite, or is supposed to be the greatest possible limit, we, in conformity with the notation hitherto used, would write those expres-

sions respectively $\overset{r}{\underset{m}{\overset{p}{\underset{C}{\overset{n}{___}}}}}$, $\overset{r}{\underset{m}{\overset{p}{\underset{}{\overset{n}{a, b, c, \&c.}}}}}$, $\overset{r}{\underset{r}{\overset{p}{\underset{}{\overset{n}{a, b, c, \&c.}}}}}$, when $p = o$, and the time m is not the utmost limit, they will stand $\overset{r}{\underset{m}{\overset{o}{\underset{C}{\overset{n}{___}}}}}$ $\overset{r}{\underset{m}{\overset{o}{\underset{}{\overset{n}{a, b, c, \&c.}}}}}$ $\overset{r}{\underset{r}{\overset{o}{\underset{}{\overset{n}{a, b, c, \&c.}}}}}$: and when m is the utmost limit, and $p = o$, they will stand $\overset{r}{\underset{C}{\overset{o}{\overset{n}{___}}}}$ $\overset{r}{\underset{}{\overset{o}{\overset{n}{a, b, c, \&c.}}}}$, &c. These denote the assurances of one pound to be received after the failure takes place; and if they be multiplied by r^p, they will denote the value of the assurance, if the money be to be received at the time p after the event takes place, whenever that may happen between the times n and m; and this is *properly what should be called the assurance* of the sums, though writers call what I denote by $\overset{r}{\underset{C}{\overset{p}{\overset{n}{___}}}}$ $\overset{r}{\underset{m}{\overset{p}{\underset{}{\overset{n}{a, b, c, \&c.}}}}}$, &c. the assurance. See Scholium.

Art. 10. It is often necessary in calculating from tables, to have a method of interpolation for the discovery of terms not explicitly contained in the tables; if, for instance, we had the function $M_{x, y, z, \&c.}$ calculated in a table, for values of x, y, z, &c. taken in as many series proceeding in arithmetical progression, according to certain scales of differences, and we wish to have the value of the function, when some only, or neither of them are in those series. And for this purpose the method of finite differences, when the differences converge, is applied with great advantage, as is well known.

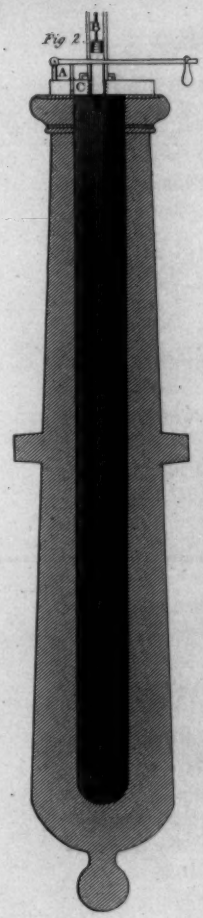


Fig 2.
A
C

Fig 1.
D
E
C
A
B

Fig 3.
E
C
D
B

Fig 3.
E
C
A
D
B

By the prefixed symbols Δ, Δ^2, Δ^3, &c., I mean the first, second, and third differences of the function to which it is prefixed, arising from the series formed by writing x, $x+i$, $x+2i$, $x+3i$, &c. in the place of x in that function. Hence from the method of differences we have

$$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a+a} = \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a} + \frac{a}{i}\cdot\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta_{a\,:\,i}|}}}}\underline{a} + \frac{a}{i}\times\frac{\frac{a}{i}-1}{2}\cdot\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta^2_{a\,:\,i}|}}}}\underline{a} + \&c.$$

$$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a+a,b,c,\&c.} = \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a,b,c,\&c.} + \frac{a}{i}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta_{a\,:\,i}|}}}}\underline{a,b,c,\&c.} + \frac{a}{i}\cdot\frac{\frac{a}{i}-1}{2}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta^2_{a\,:\,i}|}}}}\underline{a,b,c,\&c.} + \&c.$$

$$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a+a,b+\beta,c,\&c.} = \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a,b,c,\&c.} + \frac{a}{i}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta_{a\,:\,i}|}}}}\underline{a,b,c,\&c.} + \frac{a}{i}\cdot\frac{\frac{a}{i}-1}{2}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta^2_{a\,:\,i}|}}}}\underline{a,b,c,\&c.}, \&c.$$

$$+\frac{\beta}{w}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta_{\beta\,:\,w}|}}}}\underline{a,b,c,\&c.} + \frac{a}{i}\cdot\frac{\beta}{w}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta\Delta_{a\,:\,i\;\beta\,:\,w}|}}}}\underline{a,b,c,\&c.}, \&c.$$

$$+\frac{\beta}{w}\frac{\frac{\beta}{w}-1}{2}\overset{r}{\underset{m}{\overset{p}{\underset{n}{\Delta^2_{\beta\,:\,w}|}}}}\underline{a,b,c,\&c.}, \&c.$$

And in a similar manner are other expressions written. It may be often of advantage, where the text is sufficiently explicit, to use the differencing symbols and omit the others, leaving them to be understood, and to write, for instance,

$$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a+a,b+\beta,c,\&c.} =$$

$$\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\underline{a,b,c,} + \frac{a}{i}\Delta_{a\,:\,i} + \frac{a}{i}\cdot\frac{\frac{a}{i}-1}{2}\Delta_{a\,:\,i} + \&c.$$

$$+\frac{\beta}{w}\Delta_{\beta\,:\,w} + \frac{a}{i}\cdot\frac{\beta}{w}\Delta\Delta_{a\,:\,i\;\beta\,:\,w} + \&c.$$

$$\frac{\beta}{w}\cdot\frac{\frac{\beta}{w}-1}{2}\Delta_{\beta\,:\,w} + \&c.$$

SECTION II. Art. 1. If there be any function M_x, which decreases as x increases, and for x we write $x+n$, the function will be transformed into M_{x+n}; and may be developed into $M_x - n M'_x + n^2 M''_x + n^3 M'''_x$, &c. where M'_x is positive; and if m be taken sufficiently small we shall have $M_{x+n} = M_x - n M'_x$ sufficiently near. And $n M'_x$ will be nearly the decrement produced in M_x by writing $x+n$ for x. And this *approximative* decrement is proportional to n. Hence it appears, that the number of persons living in any table of mortality indicating the number of persons living at every possible age, that is to any fraction of a year or unity of time, the intervals of age may be taken so small, that whatever the law of mortality may be, during any portion of any the same interval, the decrements may be considered proportional to the time. Observation informs us, that this proportionality of decrement may be admitted as affording a tolerable degree of accuracy during very long intervals, and in that respect, it gives us some idea of the nature of the function of mortality; but independently of observations from known results, we see that we may approximate to any degree of accuracy contained in the tables, by dividing long intervals into shorter intervals, and taking, whatever may be the functions of mortality or of living, the decrements proportional to the portions of time between the separate intervals, and thus if we wished to find the value of $\overset{r}{\underset{m}{\overset{1}{\underset{n}{|}}}} a, b, c,$ &c., that is the value of an annuity of one pound on the joint lives whose present ages are $a, b, c,$ &c.; the first payment to be made in the time n, and the last in the time m, at a rate per cent. indicated by the

present worth r of one pound to be received, certain in one one year; because $\overset{r}{\underset{m}{\overset{1}{\underset{n}{|}}}}a, b, c, \&c. = (r^n . L_{n:a,b,c,\&c.} + r^{n+1} . L_{n+1:a,b,c,\&c.} + \&c. \ldots\ldots r^m L_{m:a,b,c,\&c.})$ divided by $L_{a,b,c,\&c.}$ it follows that if the interval be taken sufficiently small, the decrements being considered proportional to the time, and ρ be taken not greater than $m-n$, we shall have $r^{n+\rho} . L_{n+\rho:a,b,c,} = r^{n+\rho} \times L_{n+\rho} - \rho L'_{n+\rho} \times L_{b+n} - \rho L'_{b+n} \times L_{c+n} - \rho . L'_{c+n} \times \&c.$, by using, *mutatis mutandis*, the notation above, and this is $= r^{n+\rho} . (L_{n:a,b,c,\&c.} - \rho (L'_{n+a} . L_{n:b,c,\&c.} + L'_{n+b} . L_{n:a,c,\&c.} + \&c.) + \rho^2 . (L'_{n+a} . L'_{n+b} . L_{n:c,\&c.} + \&c.) - \&c.) = r^{n+\rho} . L_{n:a,b,c,\&c.} \times (A_n \rho + B_n \rho^2 - \&c.)$; A_n, B_n, &c. being put for the coefficients of the different powers of ρ, are constant during the interval of uniform decrement, and consequently, by writing $o, 1, 2, 3$, &c. for ρ, we see how we may obtain the value of annuities approximately for portions of time sufficiently small, and that we therefore have

$$\overset{\rho}{\underset{m}{\overset{1}{\underset{n}{|}}}}a, b, c, \&c. = r^n . \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \times \left\{ \begin{array}{llll} \frac{1}{r} & - A_n \frac{o}{r} & & + B_n \frac{o}{r} - \&c. \\ r^o & 1 r^o & & 2 r^o \\ r^2 & 3 r^2 & & 9 r^2 \\ \&c. & \&c. & & \&c. \\ r^{n-m} & n-m . r^{n-m} & & n-m r^{n-m} \end{array} \right\}$$

and if T_{n-m} be put $= 1 + r + r^2 \ldots\ldots r^{n-m}$, $T'_{n-m} = r + 2r^2 + 3r^3 + 4r^4 \ldots\ldots n-m . r^{n-m}$, $T'' = r + 4r^2 + 9r^3 \ldots\ldots n-m^2 . r^{n-m}$, &c., numerical values of which may be arranged in a small table, we shall have $\overset{r}{\underset{m}{\overset{1}{\underset{n}{|}}}}a, b, c, \&c. = r^m . \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c}} \times (T_{n-m} - A_n T_{n-m} + B_n T''_{n-m} - \&c.)$ and by repetition and addition we may obtain $\overset{r}{\underset{n}{\overset{1}{|}}}a, b, c, \&c.$, that is the value of the

annuity on the whole possible joint existence: and where there are many lives concerned, perhaps this may answer with as little trouble as by the common methods by the limited tables; and any accuracy may be obtained that the tables of mortality will afford, by using sufficiently small intervals; which is not the case when the common method is used, of searching in the tables of two joint lives, and then of a single life, and then of another life with this single life, &c. till we have comprehended the whole number of lives.

Art. 2. Moreover any functions M_{x+m}, may be developed into the form $M_x \cdot \pi^{mM'_x + m^2 M''_x + \&c.}$ and, consequently, if n be sufficiently small to admit of all powers of n above the first being omitted, we shall have $M_{x+m} = M_x \cdot \pi^{mM'_x}$; and if this remark be applied to the function L_{a+n} of the living at the age $a+n$, we see that we may take an interval m, from n so small, whatever be the real constitution of the function, that the number of the living, during that interval, shall decrease so as to form a geometrical progression very nearly, whilst the portions of time increase in an arithmetical progression; and that the decrements of living are also in consequence very nearly in geometrical progression: and we may moreover in this, as in the former case, accommodate the function so as to be accurate at the two extremes. Thus, for instance, if we wish to have an *approximative* expression in a geometrical progression, for the number of living for ages from 20 to 30 years, which shall be exact for the age 20 and 30, according to the Northampton tables of mortality. Assume π any convenient number at pleasure, say 10, take $a = 20$, and $a + n = 30$; $\therefore n = 10$,

and we have $L'_x = L'_{20} = \frac{\text{Log. of } L_{30} - \text{Log. of } L_{20}}{10} = -,0068317$ according to the Northampton tables. And when n is any thing from 0 to 10, $L_{20+n} = L_{20} \cdot 10^{-.0068317n}$, and the logarithm of the numbers of living at the age $20+n = 3,7102866 - 0068317n$. Hence we have respectively

Living at the ages	20	21	22	23	24	25	26	27	28	29	30
According to the Northampton Table	5132	5060	4985	4910	4835	4760	4685	4610	4535	4460	4385
Ditto, Geometrical progression - -	5132	5051	4972	4895	4819	4744	4670	9457	4525	4454	4385
Deficiency of the Geometrical progression	0	9	13	15	16	16	15	13	10	6	0

Art. 3. Hence, if we consider $L_{x+r} = L_x \cdot \overline{10}|^{r \cdot L'_x}$, whilst r is not greater than $m-n$ as a sufficient approximation; and we wish to find the value of $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} a, b, c, \&c.$ we have by writing ρ for the common logarithm of r, and putting $\rho + L'_{a+n} + L'_{b+n} + L'_{c+n} + \&c. = \mu$, $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} a, b, c, \&c. = \overline{10}|^{n\rho} \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \times (1 + \overline{10}|^{p\mu} + \overline{10}|^{2p\mu} + \overline{10}|^{3p\mu} + \ldots\ldots \overline{10}|^{\overline{m-n}\,p\mu}) = \overline{10}|^{n\rho} \cdot \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \times \frac{1-10^{(m-n+p)\mu}}{1-10^{p\mu}}$; and by restorations this may be written

$$r^n \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \times \frac{1 - r^{m-n+p} \frac{L_{m+p:a,b,c,\&c.}}{L_{n:a,b,c,\&c.}}}{1 - r^p \cdot \frac{L_{n+p:a,b,c,\&c.}}{L_{n:a,b,c,\&c.}}}$$

Art. 4. If the number of living, corresponding to times in arithmetical progression, form a series in geometrical progression, we should have

$$\overset{r}{\underset{m}{\overset{\rho}{\underset{\pi}{\overset{\rho}{\underset{\pi}{\overset{\rho}{\underset{\pi

may be considered the general practice, must often lead to error.

It may be worth observing, that if $L_{a+n}, L_{b+n}, L_{c+n}$, &c. were respectively equal to $L_a \cdot \pi^{n L'_a}, L_b \cdot \pi^{n L'_b}, L_c \pi^{n L'_c}$, &c. whatever positive value n might be, that is, if the living from the respective ages a, b, c, &c., whilst the time increased in arithmetical progression form series in a geometrical progression, then would the present value of the periodic income on the joint lives of the ages a, b, c, &c. be the same for the same term, as on ages older than those by any number of years, either the same for each, or different. And hence we may have some reason to suspect that the value of annuities given by tables on old age, by assuming a necessary term to life, as is done in the adopted tables of mortality, is likely to be far from the truth.

Art. 5. As to the calculations of the values of $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c.}{\quad}$, $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}\frac{a, b, c, \&c. : a', b', c', \&c. : \&c.}{\quad}$. See Art. 6 and 7. Sect. 1, and other expressions therein contained. Besides the usual mode of reducing them to their equivalents, a number of combinations of joint lives, for the purpose of working from calculated tables, which, when the lives are many, will be a laborious task, and subject to the errors of numerous interpolations and of the other approximative modes which will be necessary in many cases when the lives are numerous, it may be easier to work them directly without such reduction, or by reducing the terms to geometrical progressions for short

periods, &c. and for all these purposes it is necessary to have the value of the contingencies referring to each payment. And in order to this, for the sake of brevity, let $E_{a,n}$ whatever a and n may be, represent the chance that a person of the age a, shall be living at the expiration of the time n, and $D_{a,n}$ be the chance of his being dead at the expiration of the time n. And consequently, $E_{a,n} + D_{a,n} = 1$; also $F_{a,n} = \frac{L_{a+n}}{L_a}$, and $D_{a,n} = 1 - \frac{L_{a+n}}{L_a}$. Moreover, if we introduce any letter x as a multiplier of $E_{a,n}$, if x be equal to unity, since $E_{a,n} = x \cdot E_{a,n}$, we may under that idea of x being $=$ unity, write $x \cdot E_{a,n} + D_{a,n} = 1$, $x E_{a,n} + D_{c,n} = 1$, &c.; and also $(x E_{a,n} + D_{a,n}) \times (x E_{b,n} + D_{b,n}) \times \overline{(x E_{c,n} + D_{c,n})} + \&c. = 1$; and if the left hand side be multiplied out at length, and there be μ persons or μ multipliers, then the coefficient of x^{μ} will be the chance that all the μ persons shall be living, the coefficient of $x^{\mu-1}$ will be the chance that there shall be $\mu-1$ and no more living, the coefficient of $x^{\mu-2}$ will be the chance that there shall be $\mu-2$ and no more living, and generally the coefficient of $x^{\mu-\pi}$ the chance that there shall be exactly $\mu-\pi$ of them living, and the sum of all the coefficients from that of x^{μ} to that of $x^{\mu-\pi}$ both included, will be the chance that there shall be $\mu-\pi$ or more of them living. If we write $1-E_{n,a}$ for $D_{a,n}$ our equation will stand $\overline{x-1} \cdot E_{a,n} + 1 \times \overline{x-1} \cdot E_{b,n} + 1 \times \overline{x-1} \cdot E_{c,n} + 1$, &c. to μ terms $= 1$, x being supposed equal to unity. This is an identical equation, and if for the sake of brevity we put $P_{\mu,\pi} =$

the product of all the μ terms $E_{a,n}$, $E_{b,n}$, $E_{c,n}$, &c., $P_{\mu-1,1}$ = the sum of the products of every $\mu-1$ terms, $P_{\mu-2,2}$ the sum of the product of $\mu-2$ terms, &c. the equation will stand $\overline{x-1}|^{\mu} . P_{\mu,0} + \overline{x-1}|^{\mu-1} . P_{\mu-1,1} + \overline{x-1}|^{\mu-2} . P_{\mu-2,2}$ &c. $= 1$, when $x = 1$; that is

$$x^{\mu} P_{\mu,0} - \mu . x^{\mu-1} . P_{\mu,0} + \mu . \frac{\mu-1}{2} . x^{\mu-2} . P_{\mu,0} - \mu . \frac{\mu-1}{2} . \frac{\mu-2}{3} . x^{\mu-3} . P_{\mu,0}, \text{ &c.}$$
$$+ x^{\mu-1} . P_{\mu-1,1} - \frac{\mu-1}{1} . x^{\mu-2} . P_{\mu-1,1} + \frac{\mu-1}{1} . \frac{\mu-2}{2} . x^{\mu-3} P_{\mu-1,1}, \text{ &c.}$$
$$+ x^{\mu-2} P_{\mu-2,2} - \frac{\mu-2}{1} x^{\mu-3} P_{\mu-2,2}, \text{ &c.}$$
$$+ x^{\mu-3} P_{\mu-3,3} - \text{ &c.}$$

And the coefficient of $x^{\mu-\pi}$ or the chance of their being at the expiration of the time,

Just $\mu-\pi$ living is $P_{\mu-\pi,\pi} - \frac{\mu-\pi+1}{1} . P_{\mu-\pi+1,\pi-1} + \frac{\mu-\pi+2}{1} . \frac{\mu-\pi+1}{2} . P_{\mu-\pi+2,\pi-2} -$ &c.

Ditto $\mu-\pi+1$. is $+ P_{\mu-\pi+1,\pi-1} - \frac{\mu-\pi+2}{1} . P_{\mu-\pi+2,\pi-2}$ &c.

Ditto $\mu-\pi+2$. is $- - - - - P_{\mu-\pi+2,\pi-2}$ &c.

&c. &c.

and the sum of these, or the chance that there shall be $\mu-\pi$ or more living, is $= P_{\mu-\pi,\pi} - \overline{\mu-\pi} . P_{\mu-\pi+1,\pi-1} + \overline{\mu-\pi} . \frac{\mu-\pi+1}{2} . P_{\mu-\pi+2,\pi-2}$ &c. Similarly if x, x', x'', &c. be each unity, we have the identical equations $\overline{x-1} . E_{a,n} + 1 \times \overline{x-1} . E_{b,n} + 1 \times \overline{x-1} E_{c,n} + 1$, &c. $\times \overline{x'-1} . E_{a',n} + 1 \times \overline{x'-1} . E_{b',n} + 1 \times \overline{x'-1} . E_{c',n} + 1$ &c. $\times \overline{x''-1} . E_{a'',n} + 1 \times \overline{x''-1} . E_{b'',n} + 1$ &c. $= 1$, and the coefficient of $x^{\pi} \times x'^{\pi'} \times x''^{\pi''}$ will be the chance of there being exactly π living of the first set, π' living of the second set, π'' living of the third set, &c. We remark by the bye, that if a, b, c, &c. be equal to each other, then the equation $\overline{x-1} . E_{a,n} + 1 \times \overline{x-1} . E_{b,n} + 1 \times$ &c. to μ terms $= 1$, will be $\overline{x-1} . E_{a,n} + 1|^{\mu} = 1$, and that $\overline{x-1} . E_{a,n} + 1|^{\mu}$ being

$= \overline{x-1}\Big|^{\mu} E^{\mu}_{a,n} + \mu \cdot \overline{x-1}\Big|^{\mu-1} E^{\mu-1}_{a,n} + \mu \cdot \frac{\mu-2}{2} \cdot \overline{x-1}\Big|^{\mu-2} \cdot E^{\mu-2}$ &c. therefore in this case $P_{\mu,0} = E^{\mu}_{a,n}$, $P_{\mu-1,1} = \mu \cdot E^{\mu-1}_{a,n}$, $P_{\mu-2,2} = \mu \cdot \frac{\mu-1}{2} E^{\mu-2}_{a,n}$, &c.

SECTION 3, being necessary Lemmata.

Art. 1, on the fluent of $L_{q+x} \cdot \dot{L}_{r+x}$.

Suppose that between the intervals $x=n$ and $x=n+m$, the decrements of life of persons arrived at the ages $q+n$, $r+n$, each in proportion to the time elapsed from the commencement of the interval, or that they may be considered so with sufficient accuracy. See Sect. II. Art. 1. Put $x=n+t$, L_{q+x}, or $L_{q+n+t} = L_{q+n} - t L'_{q+n}$, $L_{r+x} = L_{r+n} - t L'_{r+n}$; and the fluent of $L_{q+x} \cdot \dot{L}_{r+x}$ will be = fluent of $(-L'_{r+n} \dot{t} \times \overline{L_{q+n} - t L'_{q+n}})$ = correction $- t L'_{r+n} \cdot L_{q+n} + \frac{t^2}{2} \cdot L'_{r+n} \cdot L'_{q+n}$; and as $\overset{x}{\underset{n}{\overset{o}{\overset{o}{\Big|}}}} L_{q+y} \cdot \dot{L}_{r+x}$ (Art. 3. Sect. I.) expresses the fluent of $L_{r+x} \cdot \dot{L}_{r+x}$ from $x=o$ to $x=n$, this will be the correction, if the fluent be supposed to commence from $x=o$, and our fluent that is $\overset{x}{\underset{n+t}{\overset{o}{\overset{o}{\Big|}}}} L_{q+x} \cdot \dot{L}_{r+x}$ will stand $= \overset{x}{\underset{n}{\overset{o}{\overset{o}{\Big|}}}} L_{q+x} \cdot \dot{L}_{r+x} - t L'_{r+n} \cdot L_{q+n} + \frac{t^2}{2} \cdot L'_{r+n} \cdot L'_{q+n} = \overset{x}{\underset{n}{\overset{o}{\overset{o}{\Big|}}}} L_{q+x} \cdot L_{r+x} - t L'_{r+n} \cdot (L_{q+n} - \frac{1}{2} t' L_{q+n})$; but because according to hypothesis $t L'_{q+n} = L_{q+n} - L_{q+n+t}$; $L_{q+n+\frac{1}{2}t} = L_{q+n} - \frac{1}{2} t L'_{q+n}$; and also $t L'_{r+n} = L_{r+n} - L_{r+n+t}$; therefore $\overset{x}{\underset{n+t}{\overset{o}{\overset{o}{\Big|}}}} L_{q+x} \cdot \dot{L}_{r+x}$ the fluent

in question may be written in either of the two forms $\overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - \frac{1}{2}(L_{r+n} - L_{r+n+t}) \times (L_{q+n} + L_{q+n+t})$, or $\overset{r}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - (L_{r+n} - L_{r+n+t}) \times L_{q+n+\frac{1}{2}t}$, that is by reduction in either of the two forms $\overset{r}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - \frac{1}{2} L_{r+n} \cdot L_{q+n} + \frac{1}{2} L_{q+n} \cdot L_{r+n+t} - \frac{1}{2} L_{q+n+t} \cdot L_{r+n} + \frac{1}{2} L_{r+n+t} \cdot L_{q+n+t}$ or $\overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - L_{r+n} \cdot L_{q+n+\frac{1}{2}t} + L_{r+n+t} \cdot L_{q+n\frac{1}{2}t}$; that is by using the abbreviation of Art. 4. Section 1, $\overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - \frac{1}{2} L_{r+n,\, q+n} + \frac{1}{2} L_{q+n,\, r+n+t} - \frac{1}{2} L_{q+n+t,\, r+n} + \frac{1}{2} L_{r+n+t,\, q+n+t}$ or $\overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - L_{r+n,\, q+n+\frac{1}{2}t} + L_{r+n+t,\, q+n+\frac{1}{2}t}$.

Art. 2. Hence, if the deaths cannot be considered as the times, with sufficient accuracy, during the period x; but during any portion of the limits o and s, s and s', s' and s'', s'' and s''', &c. the deaths produced in any portion of the same limits, are proportional to the portions of time in which they are produced, or may be considered so with sufficient accuracy, then as we shall have $\overset{x}{\underset{o}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} = o$, we shall have $\overset{x}{\underset{s}{\overset{o}{\underset{o}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} = -\frac{1}{2} L_{r,q} + \frac{1}{2} L_{q,r+s} - \frac{1}{2} L_{q+s,r} + \frac{1}{2} L_{r+s,q+s}$;

and also $= -L_{r,q+\frac{1}{2}} + L_{r+\epsilon,q+\frac{1}{2}}$; this appears by merely writing o for n and ϵ for t in the above formulæ. And if we now write ϵ for n, and ϵ' for t in the forms of Art. 1, we shall have $\left.\begin{matrix}x\\o\\\epsilon+\epsilon'\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+x} = \left.\begin{matrix}x\\o\\\epsilon\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+x} - \frac{1}{2} L_{r+\epsilon,q+\epsilon} + \frac{1}{2} L_{q+\epsilon,r+\epsilon+\epsilon'} - \frac{1}{2} L_{q+\epsilon+\epsilon',r+\epsilon} + \frac{1}{2} L_{r+\epsilon+\epsilon',q+\epsilon+\epsilon'}$, and also $= \left.\begin{matrix}x\\o\\\epsilon\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+x} - L_{r+\epsilon,q+\epsilon+\frac{1}{2}\epsilon'} + L_{r+\epsilon+\epsilon',q+\epsilon+\frac{1}{2}\epsilon'}$. And by continuing in this manner, we shall arrive at the value of $\left.\begin{matrix}x\\o\\n\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+1}$, where $n = \epsilon + \epsilon' + \epsilon''$ + &c.; and therefore by dividing the intervals into a sufficient number, we may find the fluent of $L_{q+x} \cdot \dot{L}_{r+x}$ to the utmost degree of accuracy, that the tables of mortality will admit of; and for most purposes, by dividing the time in but few intervals, the requisite accuracy will be obtained.

Art. 3. And considering the decrements also equal during the interval m at the expiration of the interval n, we have $\left.\begin{matrix}x\\o\\n+m\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+x}$, that is the fluent of $L_{q+x} \cdot \dot{L}_{r+x}$ from $x=o$ to $x=n+m$, $= \left.\begin{matrix}x\\o\\n\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+x} - \frac{1}{2} L_{q+n,r+n} + \frac{1}{2} L_{q+n,r+n+m}$, $- \frac{1}{2} L_{q+n+m,r+n} + \frac{1}{2} L_{q+n+m,r+n+m}$, and also $\left.\begin{matrix}r\\o\\n\end{matrix}\right| L_{q+x} \cdot \dot{L}_{r+x} - L_{r+n,q+n+\frac{1}{2}m} - L_{r+n+m,q+n+\frac{1}{2}m}$, these are obtained by writing m in the place of t in Art. 1.

Art. 4. And if $\epsilon, \epsilon', \epsilon''$, &c. m, be each equal to, or less than

the interval of the times between our tabulated numbers of living, these may generally be considered to give the utmost limit of accuracy the tables will afford; unless that there should appear sufficient regularity in the numbers of the tables to warrant a belief that an interpolation will offer a more accurate determination of the number of living for intermediate intervals than the first differences only will give; in which case our intervals s, s', &c. m, should, to obtain our confidence of their attaining the utmost accuracy, be taken smaller than the intervals of the tables, by taking their corresponding numbers by interpolations.

Art. 5. It may be observed with regard to Articles 1 and 2, that when the object is only the calculations of the value of $\overset{x}{\underset{n+t}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x}$, the less developed form $\overset{x}{\underset{n}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - (L_{r+x} - L_{r+n+t}) \cdot L_{q+n+\frac{1}{2}t}$ of its value, may be more convenient than the form $\overset{x}{\underset{n}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - L_{r+n,q+n+\frac{1}{2}t} + L_{r+n+t,q+n+\frac{1}{2}t}$; and that n being $= s+s'+s''+$ &c. we shall have $\overset{x}{\underset{n}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} = -(L_r - L_{r+s}) \cdot L_{q+\frac{1}{2}s} - (L_{r+s} - L_{r+s+s'}) \cdot L_{q+s+\frac{1}{2}s'} - (L_{r+s+s'} - L_{r+s+s'+s''}) \cdot L_{q+s+s'+\frac{1}{2}s''}$, &c.

Art. 6. From Article 2 we have $\overset{x}{\underset{s+s'}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} = \overset{x}{\underset{s}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} - \frac{1}{2} L_{r+s,q+s} + \frac{1}{2} L_{q+s,r+s+s'} - \frac{1}{2} L_{q+s+s,r+s'} + \frac{1}{2} L_{q+s+s',r+s+s'}$; but $\overset{x}{\underset{s}{\overset{0}{\overset{0}{|}}}} L_{q+x} \cdot \dot{L}_{r+x} = -$

$\frac{1}{2}L_{r,q}+\frac{1}{2}L_{q,r+s}-\frac{1}{2}L_{q+s,r}+\frac{1}{2}L_{q+s,r+s}$; and consequently $\overset{x}{\underset{s+s'}{\overset{o}{\underset{o}{\Big]}}}} L_{q+x}\cdot\dot{L}_{r+x}=-\frac{1}{2}L_{q,r}+\frac{1}{2}L_{q,r+s}-\frac{1}{2}L_{q+s,r}+\frac{1}{2}L_{q+s,r+s+s'}-\frac{1}{2}L_{q+s+s',r+s}+\frac{1}{2}L_{q+s+s',r+s+s'}$, whereas if in Art. 1, we take $n=o$ and $t=s+s'$, we shall have $\overset{x}{\underset{s+s'}{\overset{o}{\underset{o}{\Big]}}}} L_{q+x}\dot{L}_{r+x}=-\frac{1}{2}L_{q,r}+\frac{1}{2}L_{q,r+s+s'}-\frac{1}{2}L_{q+s+s'}+\frac{1}{2}L_{q+s+s,r+s+s'}$. And we are here presented with two different forms for the value of $\overset{x}{\underset{s+s'}{\overset{o}{\underset{o}{\Big]}}}} L_{q+x}\cdot\dot{L}_{r+x}$; that is of the value of the fluent of $L_{q+x}\cdot\dot{L}_{r+x}$, whilst x from o becomes $s+s'$; the latter form being on the supposition, that the decrements are proportional to the time throughout the interval $s+s'$, and the former, that they are first proportional to the time during the interval s, and that after that they are again proportional to the time through the next interval s'. The reason of adducing these two, which are commonly approximate values of $\overset{x}{\underset{s+s'}{\overset{o}{\underset{o}{\Big]}}}} L_{q+x}\cdot\dot{L}_{r+x}$, is that several ingenious authors in the solution of some of the problems hereafter to be considered, have taken as an approximation that if two persons, who were living at a particular period, are both dead at any nominated period after, within a certain limit, that it is an equal chance which of the two is the survivor; which as will appear is the natural consequence of supposing the decrements of the lives during every part of that period, to be in a constant proportion to the time elapsed from the com-

mencement of the period. But the mode of analysis pursued by those gentlemen, have led them to divide their periods continually into two, the one a period generally of several years, and the other a period of one year only, and they have calculated for the two periods separately, and added the result of the two. This mode would be given from the first of the two forms of this article, which is extremely more complex than the second form, and apparently with very little, if any advantage; for if the decrements were accurately in a constant proportion to the time from the commencement, they would be perfectly of equal value; though the one possesses so much more simple a form than the other; and when they are each but approximations, there will be but little choice to be made between them, in point of proximity, in the use they are to be made of in those problems; though there will be a vast difference in the degree of simplicity in the resulting formula.

Art. 7. Hence the value of $L_{p+x} \times$ (fluent of $L_{q+x} \cdot \dot{L}_{r+x}$ commencing with x equal to o) will form Article 3, when $x = n+i$, be $= L_{p+n+i} \times \left(\left| \begin{matrix} x \\ o \\ o \\ n \end{matrix} \right| L_{q+x} \dot{L}_{r+x} - \frac{1}{2} L_{q+n, r+n} \right) + \frac{1}{2} L_{p+n+i, q+n, r+n+i} - \frac{1}{2} L_{p+n+i, q+n+i, r+n} + \frac{1}{2} L_{p+n+i, q+n+i, r+n+i}$; and when x becomes $n+i+i'$, supposing the uniform decrement to last through the whole period $i+i'$, the fluent will be $L_{p+n+i+i'} \times \left(\left| \begin{matrix} x \\ o \\ o \\ i+i' \end{matrix} \right| L_{q+x} \dot{L}_{r+x} - \frac{1}{2} L_{q+n, r+n} \right) + \frac{1}{2} L_{p+n+i+i', q+n, r+n+i+i'} - \frac{1}{2} L_{p+n+i+i', q+n+i+i', r+n} + \frac{1}{2} L_{p+n+i+i', q+n+i+i', r+n+i+i'}$

and the excess of this above the other, that is $\left.\begin{matrix}x\\o\\o\\n+\iota+\iota'\end{matrix}\right|(L_{p+n+\iota+\iota',q+x}\times\dot{L}_{r+x})-\left.\begin{matrix}x\\o\\o\\n+\iota\end{matrix}\right|(L_{p+n+\iota,q+x}\times\dot{L}_{r+x})$ will be $\left(\left.\begin{matrix}x\\o\\o\\n\end{matrix}\right|L_{q+x}\cdot\dot{L}_{q+x}-\frac{1}{2}L_{q+n,r+n}\right)\cdot(L_{p+n+\iota+\iota'}-L_{p+n+\iota})+\frac{1}{2}L_{q+n}\cdot(L_{n+\iota+\iota':p,r}-L_{n+\iota:p,r})-\frac{1}{2}L_{r+n}(L_{n+\iota+\iota':p,q}-L_{n+\iota:p,q})+\frac{1}{3}(L_{n+\iota+\iota':p,q,r}-L_{n+\iota:p,q,r})$ See the notation, Art. 4. Section 1.

Art. 8. If when $x=r$ and greater, $L_{q+x}\cdot\dot{L}_{r+x}$ is equal to o, and the fluent of $L_{q+x}\cdot\dot{L}_{r+x}$ generated from x equal to o becomes equal to γ, be γ, then $L_{p+x}\cdot$ fluent of $(L_{q+x}\cdot\dot{L}_{r+x}$ commencing with $x=o)$, will when $x=r+m$ be $=\gamma L_{p+\mu+\nu}$, μ being positive.

Article 9. On the fluent of $L_{p+x}\cdot L_{q-x}\cdot\dot{L}_{r+x}$, that is, if $L_{x:p,q}\cdot\dot{L}_{r+x}$ by notation, Article 4. Section 1.

If between the limits $x=n$ and $x=n+m$, the decrements of each life be sufficiently nearly proportional to the times to admit of their being considered proportional, and x being put $=n+t$, we use the notation $L_{p+x}=L_{p+n}-tL'_{p+n}$, $L_{q+x}=L_{q+n}-tL'_{q+n}$, $L_{r+x}=L_{r+n}-tL'_{r+n}$, we shall have $L_{x:p,q}\cdot\dot{L}_{r+x}=-t\dot{L}'_{r+n}\times(L_{n:p,q}-t(L_{p+n}\cdot L'_{q+n})+t^2L'_{p+n}\cdot L'_{q+n})$. Hence the fluent generated whilst x from o becomes $=n+m$ is $=\left.\begin{matrix}x\\o\\n\end{matrix}\right|L_{x:p,q}\cdot\dot{L}_{r+x}-mL'_{r+n}\cdot(L_{n:p,q}-\frac{m}{2}(L_{p+n}\cdot L'_{q+n}+L_{q+n}\cdot L'_{p+n})+\frac{m^2}{3}L'_{p+n}\cdot L'_{q+n})=$

$\overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{x:p,q} \cdot \dot{L}_{r+x} - mL'_{r+n} \cdot (L_{n+\frac{1}{2}m:p,q} + \frac{1}{12} L'_{p+n} \cdot L'_{q+n})$ since according to hypothesis $L_{p+n+\frac{1}{2}m} = L_{p+n} - \frac{1}{2} m L'_{p+n}$ and $L_{q+n+\frac{1}{2}m} = L_{q+n} - \frac{1}{2} mL'_{q+n}$; and by notations Art. 4. Section 1, $L_{n+\frac{1}{2}m:p,q}$ stands for $L_{p+n+\frac{1}{2}m} \times L_{p+n+\frac{1}{2}m}$. And we therefore have the fluent generated, whilst x from n becomes $= n+m$, that is $\overset{x}{\underset{n+m}{\overset{o}{\underset{n}{|}}}} L_{x:p,q} \cdot \dot{L}_{r+x} = -mL'_{r+n} \cdot (L_{n+\frac{1}{2}m:p,q} + \frac{1}{12} L'_{p+n} \cdot L'_{q+n})$ or its equal $-(L_{r+n} - L_{r+n+m}) \cdot L_{n+\frac{1}{2}m:p,q} - \frac{1}{12} (L_{r+n} - L_{r+n+m}) \cdot (L_{p+n} - L_{p+n+m}) \cdot (L_{q+n} - L_{q+n+m})$. And here it should be remarked, if m represents one year or less, as will be frequently the case in the application of this formula to questions of practice, that generally the part $\frac{1}{12} (L_{r+n} - L_{r+n+m}) \cdot (L_{p+n} - L_{p+n+m}) \cdot (L_{q+n} - L_{q+n+m})$ will be sufficiently small to be wholly neglected; but should greater accuracy be required, the case would be rare if it might not be considered constant throughout the possible duration of the joint lives.

Article 10. By writing $L_{q+n} - L_{q+n+m}$ for mL'_{q+n}, &c. we shall also have $\overset{x}{\underset{n+m}{\overset{o}{\underset{o}{|}}}} L_{x:p,q} \cdot \dot{L}_{r+x} = \overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{x:p,q} \cdot \dot{L}_{r+x} - (L_{r+n} - L_{r+n+m}) \times \{L_{p+n,q+n} - \frac{1}{2} L_{p+n} (L_{q+n} - L_{q+n+m}) - \frac{1}{2} L_{q+n} \cdot (L_{p+n} - L_{p+n+m}) + \frac{1}{3} (L_{q+n} - L_{q+n+m}) \cdot (L_{p+n} - L_{p+n+m})\}$

$= \overset{x}{\underset{n}{\overset{o}{\underset{o}{|}}}} L_{x:p,q} \cdot \dot{L}_{r+x} - (L_{r+n} - L_{r+n+m}) \times \{\frac{1}{3} L_{n:p,q} + \frac{1}{6}$

$$L_{n:p,q+m}+\tfrac{1}{6}L_{n:q,p+m}+\tfrac{1}{3}L_{n+m:q,p}\Big\}=\overset{x}{\underset{n}{\int}}L_{x:p,q}\cdot\dot{L}_{r+x}-$$
$$\tfrac{1}{3}L_{n:p,q,r}-\tfrac{1}{6}L_{n:r,p,q+m}-\tfrac{1}{6}L_{n:r,q,p+m}-\tfrac{1}{3}L_{n:r,q+m,p+m}+$$
$$\tfrac{4}{3}L_{n:p,q,r+m}+\tfrac{1}{6}L_{n:p,q+m,r+m}+\tfrac{1}{6}L_{n:p+m,q,r+m}+$$
$$\tfrac{2}{3}L_{n+m:p,q,r};$$

This form of developement would give the solution of some problems, to be considered in this paper, in the form which has already been given by mathematicians; but there are cases of application, in which the form in Article 9, will give a much less intricate solution.

Article 11. Because $L_{n:p,q}-\frac{m}{2}(L_{p+n}\cdot L'_{q+n}+L_{q+n}\cdot L'_{p+n})+\frac{m^2}{3}L'_{p+n}\cdot L'_{q+n}$, part of an expression of Article 9, is $=\frac{1}{2}(L_{p+n}-\frac{m}{2}\overline{1-\sqrt{\frac{1}{3}}}L'_{p+n})\cdot(L_{q+n}-\frac{m}{2}\cdot\overline{1-\sqrt{\frac{1}{3}}}\cdot L'_{p+n})+\frac{1}{2}(L_{p+n}-\frac{m}{2}\cdot\overline{1+\sqrt{\frac{1}{3}}}\cdot L'_{p+n})\cdot(L_{q+n}-\frac{m}{2}\cdot\overline{1+\frac{1}{3}}\cdot L'_{q+n})=$ agreeably to the hypothesis $\frac{1}{2}L_{n+hm:p,q}+L_{n+km:p,q}$, h being $=\frac{1}{2}-\frac{1}{2}\sqrt{\frac{1}{3}}$ and $k=\frac{1}{2}+\sqrt{\frac{1}{3}}$, and therefore the fluent of $L_{x:p,q}\cdot\dot{L}_{r+x}$ between the limits of $x=n$ and $x=n+m$ is $=\frac{1}{2}L'_{r+n}(L_{n+h:p,q}+L_{n+k:p,q})-L'_{r+n}\cdot L_{n:p,q}$.

Article 12. On the fluent of $L_{x:p,q,r,s,\&c.}\times\dot{L}_{r+x}$.

Suppose n and $n+m$ sufficiently near each other to admit the decrements to be considered with sufficient accuracy as proportional to the time t in which they are produced; t being greater than m, and $x=n+t$: and the fluent required using a similar notation to that hitherto used will be from

$t = o$ to $t = m$, equal to $-m L'_{x+n} \times L_{n:p,q,r,\&c.} - \frac{1}{2}(L'_{p+n} \cdot L_{n:q,r,s,\&c.} + L'_{q+n} L_{n,p,r,s,\&c.} + \&c.) + \&c. = -m L'_{x+n} \times L_{n+\frac{1}{2}m,p,q,r,s,\&c.}$, neglecting the remaining terms in which m^2, m^3 &c, not herein contained are concerned, as they will be small if m be small; though, if necessary, we may pursue similar means to those used in the last article.

Article 13. But if during short periods, instead of the arithmetical progressions, we use geometrical progressions, see Article 2, Section 2; and x being $= n + t$ we take $L_{p+x} = L_{p+n} \cdot \overline{10|}^{tL'_{p+n}}$, $L_{q+x} = L_{q+n} \cdot \overline{10|}^{tL'_{q+n}}$ &c., $L_{x+n} = L_{x+n} \cdot \overline{10|}^{tL'_{x+n}}$; and therefore putting π for the hyperbolical logarithm of 10, $\dot{L}_{x+n} = \pi L_{x+n} \cdot L'_{x+n} \dot{t}\,\overline{10|}^{tL'_{x+n}}$, we shall have if for the sake of brevity we put $\mu = L'_{p+n} + L'_{q+n} + L'_{r+n} + \&c. + L'_{x+n}$, $L_{w:p,q,r,s,\&c.} \times \dot{L}_{x+n} = \pi L'_{x+n} \cdot L_{n:p,q,r,s,\&c.,x} \times \dot{t} \cdot \overline{10|}^{\mu t}$, and the fluent generated whilst x from n becomes $= n + m$ is $= L_{n:p,q,r,s,\&c.,x} : \times \frac{L'_{x+n}}{\mu} \times (\overline{10|}^{\mu t} - 1) = \frac{1}{\mu} \cdot L'_{x+n} \times L_{n+m:p,q,r,\&c.,x} - L_{n:p,q,r,\&c.,x}$.

Article 14. Because $L_{x:p,q,r,\&c.,x} = L_{n:p,q,r,\&c.,x} \times \overline{10|}^{\mu t}$ and $L_{x+n} = L_{n+n} \cdot \overline{10|}^{tL'_{x+n}}$ it follows that $\frac{1}{\mu} L'_{x+n} = \frac{\text{Log : of } L_{r+x} - \text{Log of } L_{x+n}}{\text{Log : of } L_{x:p,q,r,\&c.,x} - \text{Log : of } L_{n:p,q,r,\&c.,x}}$; x being equal to $n+t$, and t any positive quantity not greater than m; the same set of geometrical series being only supposed to take effect between the intervals n and $n+m$; but if the geometrical series between those limits only take effect proximatively, our fluent will be but an approximation, though as correct as we

please by taking the intervals sufficiently small. When for the purpose of approximation a long interval is divided into smaller intervals, one of which, for instance, is from n to $n+m$, it will not be immaterial for obtaining the nearest approximation, what value we take for x between n and $n+m$, in the above value for $\frac{1}{\mu}L'_{x+n}$; an off-hand idea might be, that x should be taken somewhere about $n+\frac{1}{2}m$.

SECTION IV. Art. 1. Because $1-\frac{L_{b+x}}{L_b}$ is the chance that a person of the age b shall be dead in the time x, $-\frac{\dot{L}_{b+x}}{L}$ is the fluxion of the chance; that is the measure of the chance that he would have of dying during a finite time $\dot{x}$, on the consideration that that cause, if any should subsist, to make the deaths disproportionate to the time, should cease at the term x. And if this be multiplied by $\frac{L_{a+x}}{L_a}$, the product will represent the fluxions of the chance of the person of the present age b dying in the life time of the person of the present age a, and consequently,—fluent of $\frac{L_{a+x}\cdot\dot{L}_{b+x}}{L_{a,b}}$ is the chance that the person of the present age a has of surviving the person of the present age b. The calculation of this fluent between any limits is effected from the articles of Section 3, referring to the fluent of $L_{q+x}\cdot\dot{L}_{r+x}$. If for q and r we write a and b, and we wish to have the part of the contingency corresponding to the intervals between $x=n$ and $x=n+1$, taking $t=1$ in the first of the two forms we have it $=\frac{(L_{b+n}-L_{b+n+1})\cdot(L_{a+n}+L_{a+n+1})}{2L_{a,b}}$; and by taking n successively 0, 1, 2, 3, &c. and adding the

results; making the division by $2\,L_{a,b}$ for the sake of convenience on the sum of numerators, we obtain in the same formula excepting the notation, with the ingenious Mr. MORGAN first, and Messrs. BAILY and MILNE after him, the value of the contingency for any part or the whole of life, that the age a shall survive b. If we use the second form, the part due to the interval between n and $n+1$, will stand $\frac{L_{b+n}-L_{b+n+1}}{L_{a,b}}$ $.L_{a+n+\frac{1}{2}}$; this form, at least if the tables of mortality have the number of living inserted for every half year, would be easier in practice than the other. If a less accurate solution would answer our purpose, we might take t much larger; if it were taken ten years we should soon get through the work, and frequently with sufficient accuracy, either from the article now quoted, or from Art. 13. of the same section; that due to the interval between n and $n+t$, is $\frac{(L_{b+n}-L_{b+n+t})\cdot(L_{a+n}+L_{a+n+t})}{2\,L_{a,b}}$. or $\frac{L_{b+n}-L_{b-n+nt}}{L_{a,b}}\cdot L_{a+n+\frac{1}{2}t}$.

Art. 2. That A and B whose present ages are a and b, both die during the time; but that B dies last, is from a similar argument $=$ — fluent of $(1-\frac{L_{a+z}}{L_a})\times\frac{L_{b+z}}{L_b}=$ correction $-\frac{L_{b+z}}{L_b}+$ fluent of $\frac{L_{a+z}\cdot L_{b+z}}{L_a\cdot L_b}$; and this case may be therefore found immediately from the other; or the other case immediately from this. But if from the period $x=n$ to $x=n+m$, the decrements of each life be proportional to the times, however different the decrements of A's life and of B's life

may be; then since $-\left(1-\frac{L_{a+x}}{L_a}\right)\cdot\frac{\dot{L}_{b+x}}{L_b}$ may if $x=n+t$, according to the notation we have used be written $\left(1-\frac{L_{a+x}}{L_a}+t\frac{L'_{a+n}}{L_a}\right)\dot{t}\cdot\frac{L'_{b+n}}{L_b}$, our fluent between the limit $x=n$ and $x=n+m$, will therefore become $\left(1-\frac{L_{a+n}}{L_a}\right).m\frac{L'_{b+n}}{L_b}+\frac{m^2}{2}\cdot\frac{L'_{a+n}\cdot L'_{b+n}}{L_a\cdot L_b}$; that is agreeably to the hypothesis putting $L_{a+n}-L_{a+n+m}=m\cdot L'_{a+n}$, and $L_{b+n}-L_{b+n+m}=m\cdot L'_{b+n}$, it becomes $\left(1-\frac{L_{a+n}}{L_a}\right)\cdot\frac{L_{b+n}-L_{b+n+m}}{L_b}+\frac{L_{a+n}-L_{a+n+m}}{L_a}\times\frac{L_{b+n}-L_{b+n+m}}{2L_b}$: this if n were equal to o would be reduced to $\frac{1}{2}\left(1-\frac{L_{a+m}}{L_a}\right)\times\left(1-\frac{L_{b+m}}{L_b}\right)$; which is just half the chance that they shall both have died in that time; an approximation frequently of service, and used in many cases by Mr. MORGAN, and the Gentlemen who have followed him. If there be a term of possible joint existence, and that be when $m=\mu$; and ν be some positive quantity, the formula $\frac{1}{2}\left(1-\frac{L_{a+n}}{L_a}\right)\cdot\left(1-\frac{L_{b+m}}{L_b}\right)$ will not answer when $m=\mu+\nu$, if A be the oldest; when $\nu=o$ it will answer and become $\frac{1}{2}\left(1-\frac{L_{b+m}}{L_b}\right)$, but when ν has a value, this must be increased by the chance that B has of dying beyond this time; that is, it must be increased by $\frac{L_{b+\mu}-L_{a+\mu+\nu}}{L_b}$; but if A be youngest, it becomes when

$m = \mu + \nu$, $\frac{1}{2}\left(1 - \frac{L_{a+x}}{L_a}\right)$. Moreover, though the chance of A's surviving B, being half the chance of their both being dead, is here derived from the hypothesis of the decrement's being proportional to the time in each original age; this is not the only hypothesis which will cause that relation of the contingencies; or, which is the same thing, provided they both are to be dead, that the contingency of A's surviving B shall be equal to the contingency of B's surviving A; for the fluxion of this equation is $-\left(1 - \frac{L_{a+x}}{L_a}\right) \times \frac{\dot{L}_{b+x}}{L_b} = -\left(1 - \frac{L_{b+x}}{L_b}\right) \times \frac{\dot{L}_{a+x}}{L_a}$; and therefore $\frac{-\frac{\dot{L}_{a+x}}{L_a}}{1-\frac{L_{a+x}}{L_a}} = \frac{-\frac{\dot{L}_{b+x}}{L_b}}{1-\frac{L_{b+x}}{L_b}}$; and consequently taking the correct fluent &c. we get $1 - \frac{L_{a+x}}{L_a} = K \cdot \left(1 - \frac{L_{b+x}}{L_b}\right)$; k be a constant quantity; therefore the fluent of $\left(1 - \frac{L_{a+x}}{L_a}\right) \cdot \frac{\dot{L}_{b+x}}{L_b} =$ — the fluent of $k\left(1 - \frac{L_{b+x}}{L_b}\right) \cdot \frac{\dot{L}_{b+x}}{L_b}$; which taken to vanish when $x = o$ is the contingency according to the present hypothesis of B dying after A; and is $= k \cdot \left(1 - \frac{L_{b+x}}{L_b} - \frac{1}{2} + \frac{1}{2}\left(\frac{L_{b+x}}{L_b}\right)^2\right) = \frac{1}{2}k \cdot \left(1 - 2\frac{L_{b+x}}{L_b} + \left(\frac{L_{b+x}}{L_b}\right)^2\right) = \frac{1}{2}k \cdot \left(1 - \frac{L_{b+x}}{L_b}\right)^2 = \frac{1}{2} \cdot 1 - \frac{L_{a+x}}{L_a} \cdot 1 - \frac{L_{b+x}}{L_b}$.

Hence it appears, that whatever the decrements of life, or the constitution of the functions of life, it will be an equal

chance if A and B are both to be dead, whether A dies after B, or B dies after A, if $1 - \frac{L_{a+x}}{L_a} = k \cdot \left(1 - \frac{L_{b+x}}{L_b}\right)$, k being constant.

"*Note.* If the constitution of both functions of life is of "one and the same continuous character, which is not neces- "sarily the case, unless they be taken from one and the "same continuous table; then it becomes an interesting pro- "blem to search, what is the constitution of the function of "life, to admit of the aforesaid equality of contingency of A "dying after B or B dying after A; on the condition of their "both dying in that time; that is to say, to find the common "characteristic L which shall be independent of a, b, and x, "such that $1 - \frac{L_{a+x}}{L_a} = k \cdot \left(1 - \frac{L_{b+x}}{L_b}\right)$, the requisite equa- "tion above given. And as this is a problem which, from its "mode of solution, may be equally interesting to the Analyst, "as forming one of a rather novel species of problems, I "shall give its solution for both purposes; in order to which "I first observe, that unless k be unity, it must be expressi- "ble in the form $\frac{D_b}{D_a}$, so that the equation may be written in the "form $D_a \cdot \frac{L_{a+x}}{L_a} - D_a = D_b \cdot \frac{L_{b+x}}{L_b} - D_b$; otherwise there "would not be a perfect similarity of the character L, on both "sides of the equation. For the sake of brevity, put $\frac{D_a}{L_a} = H_a$, "and therefore $\frac{D_b}{L_b} = H_b$; and our equation will stand "$H_a \cdot (L_{a+x} - L_a) = H \cdot (L_{b+x} - L_b)$; but by TAYLOR's

" theorem $L_{a+x} = L_a + x \cdot \frac{\dot{L}_a}{a} + \frac{x^2}{2} \cdot \frac{\ddot{L}_a}{a^2}$ &c. a being taken
" constant; and also $L_{b+x} = L_b + x \cdot \frac{\dot{L}_b}{b} + \frac{x^2}{2} \cdot \frac{\ddot{L}_b}{b^2}$ &c. b
" being taken constant; therefore if these be substituted in
" the last equation, it is evident that as the thing is to re-
" main true, whatever x may be, the homologous powers of
" x must destroy each other; and consequently we must
" have, by making the comparison of the coefficients of those
" powers in the equation, $H_a \cdot \frac{\dot{L}_a}{a} = H_b \cdot \frac{\dot{L}_b}{b}$; $H_a \cdot \frac{\ddot{L}_a}{a^2} = H_b$
" $\cdot \frac{\ddot{L}_b}{b^2}$; $H_a \cdot \frac{\dddot{L}_a}{a^3} = H_b \cdot \frac{\dddot{L}_b}{b^3}$, &c.; and as this is the case what-
" ever a and b are, it follows that each side of the equation
" must be constant; therefore putting $H_a \cdot \frac{\dot{L}_a}{a} = g$, $H_a \cdot \frac{\ddot{L}_a}{L_a} = h$;
" g and h being constant quantities, we have $\frac{\ddot{L}_a}{L_a} = \frac{b}{g} \cdot \dot{a}$. And
" taking the fluent of this, we have hyp. log of $\frac{\dot{L}_a}{p^a} = \frac{b}{g} a$;
" p being some constant quantity; and this may be reduced
" to the form $\dot{L}_a = p \cdot e^a \cdot \dot{a}$, e standing for the number whose
" hyperbolical logarithm is $\frac{b}{g}$; and taking the fluent again,
" we have $L_a = e' - e'' \cdot e^a$; e, e' and e'' being independent
" constant quantities, though e'' is $= -p \cdot \frac{g}{b}$ the independence
remains because $p \cdot \frac{g}{b}$ is arbitrary. And as the equation $\dot{L}_a =$
" $pe^a \dot{a}$, makes $\ddot{L}_a = p \cdot \frac{b}{g} \cdot e^a \dot{a}^2 = \frac{b}{g} \dot{a} \dot{L}_a$; $\therefore \dddot{L}_a = \frac{b}{g} a \ddot{L}_a$;

" &c.; all the conditions are fulfilled by fulfilling the condi-
" tions that $H_a \cdot \frac{L_a}{a}$, and $H_a \cdot \frac{L_a}{a^b}$, are constant. Whence we
" find the constitution is $L_a = e' - e''.e^a$; where e', e, e'' are
" any constants at pleasure. And if I mistake not, it is the
" only function which will admit of this equality of chance
" *continuously* between persons whose mortality is formed
" from the *same function*; but if e be $= 1 + i$, and i be infi-
" nitely small, this will stand simply $L_a = e' - e'(1 + ai)$;
" or writing g' for $e' - e''$ and g'' for $e''i$, this becomes
" $L_a = g' - g''a$, the formula of equal decrements in equal
" times."

Moreover the same idea of $1 - \frac{L_{a+x}}{L_a} = k \cdot 1 - \frac{L_{b+x}}{L_b}$, causes the fluent of $\frac{L_{a+x}}{L_a} \cdot \frac{\dot{L}_{b+x}}{L_b}$ to be equal to the fluent of $k \cdot \frac{L_{b+x}}{L_b} \cdot \frac{\dot{L}_{b+x}}{L_b}$, which if taken to commence with x equal to o, will be $-\frac{1}{2}k \cdot 1 - \left(\frac{L_{b+x}}{L_b}\right)^2 = -\frac{1}{2}k \cdot \overline{1 - \frac{L_{b+x}}{L_b}} \times \overline{1 + \frac{L_{b+x}}{L_b}} = -\frac{1}{2} \cdot \overline{1 - \frac{L_{a+x}}{L_a}} \times \overline{1 + \frac{L_{b+x}}{L_b}} = -\frac{1}{2} + \frac{1}{2}\frac{L_{a+x}}{L_a} - \frac{1}{2}\frac{L_{b+x}}{L_b} + \frac{1}{2}\frac{L_{x:a,b}}{L_{a,b}}$; and this is therefore not only the fluent in question in the hypothesis of constant decrements.

Article 8. If at the interest to be made for money, one pound discounted for one year were represented by r, and we wished to have the present value of one pound, to be re-

ceived at the first of the equal periods p, after the time $n-p$ that shall happen after the death of B; provided he be survived by A; and that that event takes place between the periods $n-p$ and m; then if each separate period p, may throughout its duration, be considered within the limits of constant decrements, the value of that part due to the events happening between the periods ϖ and $\varpi+p$, (ϖ being some one of the terms $n-p$, n, $n+p$, &c.) from Article 1 of this section will be $\frac{(L_{b+\varpi}-L_{b+\varpi+p})\cdot L_{a+\varpi+\frac{1}{2}p}}{L_{a,b}}\cdot r^{\varpi+p}=\frac{L_{a-\frac{1}{2}p,\,b-p}}{L_{a,b}}$

$\times r^{\varpi+p}\cdot\frac{L_{b+\varpi,\,a+\varpi+\frac{1}{2}p}}{L_{a-\frac{1}{2}p,\,b-p}}-\frac{L_{a-\frac{1}{2}p}}{L_a}\cdot r^{\varpi+p}\cdot\frac{L_{a+\varpi+\frac{1}{2}p,\,b+\varpi+p}}{L_{a-\frac{1}{2}p,\,b}}$; and if ϖ be interpreted by $n-p$, n, $n-2p$, &c. the sum of the whole will be $\frac{L_{a-\frac{1}{2}p,\,b-p}}{L_{a,b}}\cdot\left[\begin{matrix}\mathrm{C}\\ p\\ n\\ m\end{matrix}\right|_{a-\frac{1}{2}p,\,b-p}-\frac{L_{a-\frac{1}{2}p}}{L_a}\cdot\left[\begin{matrix}\mathrm{C}\\ p\\ n\\ m\end{matrix}\right|_{a+\frac{1}{2}p,\,b}$.

If p be one year or unity, this will be $\frac{L_{a-\frac{1}{2},\,b-1}}{L_{a,b}}\times$ (the annuity for the time on the ages $a-\frac{1}{2}$ and $b-1$) $-\frac{L_{a-\frac{1}{2}}}{L_a}\times$ annuity for the time on the ages $a+\frac{1}{2}$ and b.

If the value of the contingency, due to the intervals between ϖ and $\varpi+p$, be written $\frac{\frac{1}{2}L_{\varpi:a,b}+\frac{1}{2}L_{\varpi:a+p,b}-\frac{1}{2}L_{\varpi,a,b+p}-\frac{1}{2}L_{\varpi+p:a,b}}{L_{a,b}}\cdot r^{\varpi+p}$ we may obtain the value in the forms of Messrs. MORGAN, BAILY and MILNE; for by reducing the form in the shape $\frac{1}{2}\frac{L_{\varpi:a,b}-L_{\varpi+p:a,b}}{L_{a,b}}\cdot r^{\varpi+p}$

$+\frac{1}{2}\frac{L_{b-p}}{L_b}\times r^{\varpi+p}\cdot\frac{L_{\varpi:a+p,b}}{L_{a,b-p}}-\frac{1}{2}\frac{L_{a-p}}{L_a}\cdot r^{\varpi+p}\cdot\frac{L_{\varpi:a,b+p}}{L_{a-p,b}}$, and interpreting ϖ by $n-p$, n, $n+p$, &c. we have from Section 2,

for the sum of them all $\frac{1}{2} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,b} + \frac{1}{2}\frac{L_{b-t}}{L_b} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,b-p}$

$-\frac{1}{2}\frac{L_{a-t}}{L_a} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a-p,b}$. This is the same in fact as Mr. MILNE's form, excepting something more general; in as much as it refers to the case if the assurance be temporary, and transferred at the same time, and that the interval p is not necessarily one year, and that it refers also to insurances when the contingencies are taken momentarily; but it must be remarked, that in this case p being infinitely small $\frac{1}{2}\frac{L_{b-p}}{L_b} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,b-p} - \frac{1}{2}\frac{L_{a-t}}{L_a} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a-p,b}$ will have the appearance to some readers of being equal to o; whereas that is not necessarily the case; it is true that the ratio of $\frac{L_{b-t}}{L_b} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,b-p}$ to $\frac{L_{a-t}}{L_a} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a-p,b}$ will differ infinitely little from the ratio of equality; but as they will be each of them infinite, their difference may be finite. See how to calculate this value in the Scholium Art. 3.

Article 4. A correct notation of the value in the last article is in conformity with our plan $-\overset{w}{\underset{n-p}{\overset{p}{m-p}}}\left(\frac{r^{w+p}}{L_{a,b}} \times \overset{w}{\underset{w+p}{o}}\right) L_{a+s} \cdot L_{b+w}$.

And if for L_{a+s} we write $L_a - L_{a+s}$, it will express the value of the assurance on the death of B, provided A be dead at that time, other things remaining the same. And because $\overset{w}{\underset{w+p}{o}}$

$\dot{L}_s - \dot{L}_{s+x} \cdot \dot{L}_{t+x} = L_s (L_{t+v+v} - L_{t+v}) - \overset{s}{\underset{v+p}{\dot{\cdot}}} \Big| L_{s+x} \cdot \dot{L}_{t+x}$,

and $\overset{v}{\underset{m-p}{\dot{\cdot}}} \Big| r^{v+p} \frac{L_{t+v+p} - L_{t+p}}{L_t} = - \overset{r}{\underset{m}{\dot{\cdot}}} \Big| t$; therefore the value of this contingency is $\overset{r}{\underset{m}{\dot{\cdot}}} \Big| t$ — that of the last article.

Article 5. No. 1. If there may be a continuance of certain independent events, denominated for the sake of distinction K, K′, K″, K‴, &c.; and the chances of their continuing the times w, x, y, z, &c., be denoted by K_w, K'_x, K''_y, &c. respectively, then will $1 - K_w$, $1 - K'_x$, &c. denote the corresponding chances of their not continuing during those times; $\dot{K}_w$, $\dot{K}'_x$, $\dot{K}''_y$, &c. will express the fluxions of the chances of those events continuing; and if these fluxions be taken with regard to the respective under written letters w, x, y, &c., they will be the chances of continuance of those respective events due to the finite times $\dot{w}$, $\dot{x}$, $\dot{y}$, &c. respectively, on the consideration that at the terms w, x, y, &c. the causes, if any, perturbating the proportionality to the times of the discontinuance vanishes. And under the like hypothesis would $-\dot{K}_w$, $-\dot{K}'_x$, $-\dot{K}''_y$, which are the fluxions of the chances of discontinuance, express the chances of the discontinuance taking place during the times $\dot{w}$, $\dot{x}$, $\dot{y}$, &c.

No. 2. Hence we see that $-K''_x \dot{K}'''_y$ is the fluxion of the chance of the event K‴ discontinuing, whilst K″ continues; and $-\overset{x}{\underset{m''}{\dot{\cdot}}} \Big| K''_x \cdot \dot{K}''_x$ is the chance, that between the times n''

and m'', K‴ discontinues during the time of K″'s continuing: And if y be either a constant quantity or a function of x,

$-\left.\begin{matrix} x \\ n'' \\ m'' \end{matrix}\right| K''_y \dot{K}''_x$ will denote the chance due to the time between n'' and m'', that is whilst x becomes from n'' to be equal to m''; that whatever x may be, at the time of K‴'s discontinuance, that K″ shall be in continuance at the corresponding time y.

No. 3. $-K'_y\left(\left.\begin{matrix} x \\ 0 \\ y \end{matrix}\right| K''_x \dot{K}''_x\right)$ will denote the chance that the event K′ continues during the time y; with the proviso, that the event K″ shall fall some time between the times n and y; but on the condition that whenever that event shall take place, the event K″ shall not yet have discontinued.

No. 4. And $-K'_y\left(\left.\begin{matrix} x \\ 0 \\ y \end{matrix}\right| 1-K''_x \cdot \dot{K}''_x\right)$ will express the similar chance, except that the discontinuance instead of the continuance of K″ is to take place after the discontinuance of K″.

No. 5. $\left.\begin{matrix} y \\ 0 \\ m \end{matrix}\right|\left(\dot{K}_y \left.\begin{matrix} x \\ 0 \\ y \end{matrix}\right| K'_x \dot{K}''_x\right)$ will denote the portion of the chance due to the time between n and m; of K discontinuing after the event has taken place of K″'s having discontinued during the continuance of K′; if that *super-continuance* of K′ should not take place before the time n'. And if in the above expression $1-K_x$ be written for K'_x every thing will be the same; with the exception that that part which referred to the continuance of K′, will now refer to the discontinuance of K′ having taken place.

No. 6. $\sum_{m}^{n}\left(K_x K'_{x'} \sum_{x''}^{x'} K''_{x''}\right)$ will denote the portion of chance due to the time between n and m, that K shall discontinue during the continuance of K′, on the condition that previously to that event taking place, K‴ shall after the time n' have discontinued during the continuance of K″.

And thus we might proceed to an infinite variety of cases with regard to the limits in time, with regard to the number of events, &c.; and however compounded and numerous the signs of *fluentization* and summation may be, and if this mode of enunciation be duly considered, it will be found that the meaning of the more compound cases is much easier to express and to understand, in this analytical language, than by a more elaborate phraseology; and that this mode enables us as soon as the meaning of the question is understood, granting the theory of summations and *fluentizations*, to solve it.

No. 7. By way of illustration I shall only add here, that the nature of the events to which K, K′, K″ &c. may refer, is unlimited; they may refer to single lives only, to joint lives, to joint lives connected with other joint lives, to joint lives connected with deaths, &c. And that more compounded cases may be understood, I also mention that

$\sum_{m-p}^{n-p}\left(v^{p} \sum_{x+p}^{x} K''_{x} K''_{x}\right)$ expresses the assurance of one pound to be received at the first of the equal periods p, after the time $n-p$, that shall happen after the discontinuance of K‴; provided that that discontinuance happens during the

continuance of K″; and provided also, it happens between the time $n-p$ and m; the present value of one pound certain to be received in one year being equal to r.

Article 6. As it is probable that the reader will be desirous to see the application of our theory to some of the problems which have been esteemed the most difficult, I shall consider the problems which have been solved by Mr. MORGAN, in the Philosophical Transactions; and in pursuing this object, I shall take the examples in the order in which they have been presented by Mr. BAILY, in his work on Assurances, from page 206, because that Gentleman's book was in my hand when I worked the examples. Note, that the object which I denote by p, has with those Gentlemen the particular value one year; and is supposed by them to be wholly within the limits of proportional decrement. Note also, that the present ages of A, B and C, I denote by a, b and c.

Example 1. The chance of A dying, the first of the three lives A, B, C, is by taking K″ of No. 2, in the last article $= \frac{L_{x:b,c}}{L_{b,c}}$, and $K''=\frac{L_{a+z}}{L_a}$, the fluent of $\frac{L_{x:b,c}}{L_{a,b,c}}\dot{L}_{a+x}$.

If p be within the limits of proportional decrements (that is of decrements proportionate to the times) then by Section 3, Article 9, the chance of the events happening between the times π and $\pi+p$, that is $\left.\begin{matrix}x\\ o\\ \pi\\ \pi+p\end{matrix}\right\}\frac{L_{x:b,c}}{L_{a,b,c}}\cdot\dot{L}_{a+x}$ is $\frac{L_{a+\pi}-L_{a+\pi+p}}{L_{a,b,c}}\times$

$$L_{\frac{\pi+\frac{1}{2}p:b,c}{x}}+\frac{1}{12}\frac{L_{a+\pi}-L_{a+\pi+p}}{L_a}\times\frac{L_{b+\pi}-L_{b+\pi+p}}{L_b}\times\frac{L_{c+\pi}-L_{c+\pi+p}}{L_c};$$

or if p be small; such for instance as one year, it will be

simply $\frac{L_{a+\pi} - L_{a+\pi+\rho}}{L_{a,b,c}} \cdot L_{\frac{\pi+\rho}{2}:b,c}$ very nearly; as the other part will be comparatively with this extremely small; as an instance, if ρ answered to one year; $a+\pi, b+\pi, c+\pi$, each to 34 years, and the Northampton Tables be used: the error caused by neglecting the part in question, will not amount to the thirty three thousandth part of the real value. The error towards the very commencement of life, or towards the end, is certainly greater; thus if the values of $a+\pi, b+\pi, c+\pi$ were all 90; the error with the same tables, and on the same hypothesis of decrement, would bear a nearer proportion to the real value; but would not amount to the one hundred and thirtieth part of the real value; and it should be observed in these extreme cases, the hypothesis itself is defective. Moreover, the present value of one pound to be received at the end of the time $\pi+\rho$, if the event should take place between the times π and $\pi+\rho$, will be the said expression $\times r^{\pi+\rho}$; and the sum of all the values produced by interpreting π, by $n-\rho$, n, $n+\rho$, &c. to $m-\rho$, will be the present value of the assurance of one pound on the contingency. If we wish to calculate this from tables of the values of periodic incomes; as the part due to the interval between π and $\pi+\rho$, may be expressed by neglecting the small part above alluded to,

$r^{\pi+\rho} \cdot \frac{L_{\pi:a,b+\frac{1}{2}\rho,c+\frac{1}{2}\rho}}{L_{a,b,c}} L_{\pi:a+\rho,b+\frac{1}{2}\rho,c+\frac{1}{2}\rho}$ or its equal

$r^{\pi+\rho} \cdot \frac{L_{a-\rho,b-\frac{1}{2}\rho,c-\frac{1}{2}\rho}}{L_{a,b,c}} \times \frac{L_{\pi:a,b+\frac{1}{2}\rho,c+\frac{1}{2}\rho}}{L_{a-\rho,b-\frac{1}{2}\rho,c-\frac{1}{2}\rho}} r^{\pi+\rho} \frac{L_{b-\frac{1}{2}\rho,c-\frac{1}{2}\rho}}{L_{b,c}}$

$\times \frac{L_{\pi:a+\rho,b+\frac{1}{2}\rho,c+\frac{1}{2}\rho}}{L_{a,b-\frac{1}{2}\rho,c-\frac{1}{2}\rho}}$; and therefore we have the value of the assurance equal to

$$\frac{L_{a-p,\,b-\frac{1}{2}p,\,c-\frac{1}{2}p}}{L_{a,\,b,\,c}} \times \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} a-p,\,b-\tfrac{1}{2}p,\,c-\tfrac{1}{2}p \;-\; \frac{L_{b-\frac{1}{2}p,\,c-\frac{1}{2}p}}{L_{b,\,c}} \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} a,\,b-\tfrac{1}{2}p,\,c-\tfrac{1}{2}p.$$

This is on the supposition that we have neglected the value due to the part $\frac{1}{12} r^{n+p} \times \frac{L_{a+n} - L_{a+n+p}}{L_a} \times \frac{L_{b+n} - L_{b+n+p}}{L_b} \times \frac{L_{c+n} - L_{c+n+p}}{L_c}$, as being extremely small when p is small, such for instance as one year. But I observe that a near approximation of its value in this case is one twelfth of the income certain for the term multiplied by the chance of all three dying between the intervals n and $n+p$; and as an example of $p=1$ $n=1$, and the corresponding assurance for the whole possible joint existence be required from the Northampton Tables, for three lives at the age of 30, at the interest of 3 per cent.; considering the last income possibly to be received, to be at the age 95, the term will be 65, and the *approximative* value of this neglected part, if the assurance be on £1000. to be paid for in one payment; will be $1000 \times \frac{\overline{75}^3 \times 28.45}{12 \times 43\overline{85}^3}$ = about $\frac{2845}{24.00.00}$ of one pound, which is less than three pence. If we use Article 10, Section 3, we shall obtain the same portions of the contingencies as has been used by Messrs. MORGAN and BAILY, whence &c.

" Note. I may observe that if the contingencies were as in " this example with the exception that A is to die before any " of the lives B, G, D, F, &c. the value would be

" $$\frac{L_{a-p,\,b-\frac{1}{2}p,\,c-\frac{1}{2}p,\,d-\frac{1}{2}p,\,\&c.}}{L_{a,\,b,\,c,\,d,\,\&c.}} \cdot \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}} a-p,\,b-\tfrac{1}{2}p,\,c-\tfrac{1}{2}p,\,d-\tfrac{1}{2}p,\,\&c.$$

$$\text{&c. } \frac{L_{b-\frac{1}{p},\, c-\frac{1}{p},\, d-\frac{1}{p},\, \&c.}}{L_{b,\, c,\, d,\, \&c.}} \times \frac{r}{m}\Big|_{n}^{p}\, a, b-\tfrac{1}{p}, c-\tfrac{1}{p}, d-\tfrac{1}{p}, \text{ \&c. very nearly.}$$

Note also, that if the lives be all equal, and there be q of them in number, the contingency of one in particular dying before the rest will be $-$ fluent of $\overline{\frac{L_{a+x}}{L_a}}^{q-1} \dot{L}_{a+x} =$ (if it commences with $x=o$) $\frac{1}{q}\left(1-\overline{\frac{L_{a+x}}{L_a}}^{q}\right)$ and the assurance on that contingency will be $\frac{1}{q} \times$ the assurance on the joint lives.

Example 2. In a similar manner from Art. 2. No. 5, of this section, writing $\frac{L_{c+x}}{L_c} \cdot \overline{1-\frac{L_{b+x}}{L_b}} + \overline{1-\frac{L_{c+x}}{L_c}} \cdot \frac{L_{b+x}}{L_b}$ for K″, and $\frac{L_{a+x}}{L_a}$ for K‴, we have the contingency that A is the second which fails of the three lives A, B, C $=-$ fluent of $\left(\frac{L_{c+x}}{L_{c,\, a}} \cdot \dot{L}_{a+x} + \frac{L_{b+x}}{L_{b,\, a}} \cdot \dot{L}_{a+x} - \frac{2L_{x:\, b,\, c}}{L_{a,\, b,\, c}} \cdot \dot{L}_{a+x}\right) =$ chance of A's dying before C $+$ that of A's dying before B $-$ twice the chance of A's dying before B and A; and the assurance is in a similar manner made up of the assurances on the like contingencies as Messrs. MORGAN, &c. have shown.

Example 3. If K″ be put $= \overline{1-\frac{L_{b+x}}{L_b}} \times \overline{1-\frac{L_{c+x}}{L_c}}$; that is $1-\frac{L_{c+x}}{L_c}-\frac{L_{b+x}}{L_b}+\frac{L_{b+x} \cdot L_{c+x}}{L_{b,\, c}}$, and K‴$=\frac{L_{a+x}}{L_a}$, in the same article No. 2; we shall have the contingency of A's being the last which fails of the three lives $=-$ fluent of $\left(\frac{\dot{L}_{a+x}}{L_a}\right.$

$-\frac{L_{b+x}\cdot\dot{L}_{a+x}}{L_{b,a}}-\frac{L_{c+x}\cdot\dot{L}_{a+x}}{L_{c,a}}+\frac{L_{x:b,c}\cdot\dot{L}_{a+x}}{L_{a,b,c}}\Big)$; hence the assurance on this contingency is equal to the assurance on A's death, assurance on A's death if survived by B,—assurance on A's death if survived by C + assurance on A's death if survived by B and C, as Mr. MORGAN, &c. makes it.

Example 4. If $K''=1-\left(1-\frac{L_{c+x}}{L_c}\right).\left(1-\frac{L_{b+x}}{L_b}\right)$ and $K'''=\frac{\dot{L}_{a+x}}{L_a}$, we shall see that the contingency of A's dying, and that he is the 1st or 2nd which dies, is equal to — the fluent $\frac{\dot{L}_{a+x}}{L_a}\times\left(\frac{L_{c+x}}{L_c}+\frac{L_{b+x}}{L_b}-\frac{L_{c+x}\cdot L_{b+x}}{L_{c,b}}\right)$. Hence, &c.

Example 5. If A is to be the second or third which fails, by taking $K''=1-\frac{L_{x:b,c}}{L_{b,c}}$, namely, the chance that B and C are not both living, we have the contingency of A's death $=-$ fluent $\overline{1-\frac{L_{x:b,c}}{L_{b,c}}}.\frac{\dot{L}_{a+x}}{L_a}$. Hence, &c. And the assurance equal to the assurance of A's life absolutely—the assurance of his life on condition that he dies first.

Example 6. If A is either to be the first or last to die: then is the chance on his death equal to — fluent of $\frac{\dot{L}_{a+x}}{L_a}\times\left(\frac{L_{x:b,c}}{L_{b,c}}+\overline{1-\frac{L_{b+x}}{L_b}}.\overline{1-\frac{L_{c+x}}{L_c}}\right)=-$ fluent of $\dot{L}_{a+x}\times\left(1-\frac{L_{b+x}}{L_b}-\frac{L_{c+x}}{L_c}+2\frac{L_{x:b,c}}{L_{b,c}}\right)$. Hence, &c.

Example 7. To find the contingency on the first of the two

death A and B, provided that that be the first or last which dies of the three A, B, C. Here I first take $K'' = \frac{L_{x:b,c}}{L_{b,c}}$ and $K''' = \frac{L_{a+x}}{L_a}$; and then take $K'' = \frac{L_{x:a,c}}{L_{a,c}}$ and $K''' = \frac{L_{b+x}}{L_b}$; and I find the contingency $= -$ fluent of $\left(\frac{\dot{L}_{a+x}}{L_a} \cdot \frac{L_{x:b,c}}{L_b} + \frac{L_{b+x}}{L_c} \cdot \frac{L_{x:a,c}}{L_{a,c}}\right) = -$ fluent of $\frac{L_{c+x}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)^{\cdot} =$ correction $- \frac{L_{x:a,b,c}}{L_{a,b,c}}$ $+$ fluent of $\frac{L_{x:a,b}}{L_{a,b}} \cdot \frac{L_{c+x}}{L_c}$. Note, the word correction might have been omitted by considering it implicitly contained in the word fluent. Hence the assurance on the first of the deaths of A and B, provided it be the first to fail of the three A, B, C, is equal to the absolute assurance on the three joint lives, less the assurance on C's life, provided he dies first: the same as Mr. BAILY makes it in a note at page 240; by comparing the result of his solution with a former solution; but I should observe there is a typographical error in the note, by inserting $+$ ABC instead of $-$ ABC.

Example 8. If the first of the deaths of A and B, is to be the second of the three; in this case taking first $K'' = 1 - \frac{L_{b+x}}{L_g} \cdot \frac{L_{c+x}}{L_c} + 1 - \frac{L_{c+x}}{L_c} \cdot \frac{L_{b+x}}{L_b}$ and $K''' = \frac{L_{a+x}}{L_a}$, and then $K'' = 1 - \frac{L_{a+x}}{L_a} \cdot \frac{L_{c+x}}{L_c} + 1 - \frac{L_{c+x}}{L_c} \cdot \frac{L_{a+x}}{L_a}$ and $K''' = \frac{L_{b+x}}{L_b}$, we get the contingency $= -$ fluent of $\left\{\frac{\dot{L}_{a+x}}{L_a}\left(\frac{L_{c+x}}{L_c} + \frac{L_{b+x}}{L_b} - \frac{2L_{x:b,c}}{L_{b,c}}\right) + \frac{\dot{L}_{b+x}}{L_b}\right.$

$\left(\frac{L_{c+x}}{L_c}+\frac{L_{a+x}}{L_a}-\frac{2L_{x:a,c}}{L_{a,c}}\right)\Big\}=$ correction $-\frac{L_{x:a,b}}{L_{a,b}}-$ fluent of $\left(\frac{L_{a+x}}{L_a}\cdot\frac{L_{c+x}}{L_c}+\frac{L_{b+x}\cdot L_{c+x}}{L_b\cdot L_c}-\frac{2L_{x:b,c}}{L_{b,c}}\cdot\frac{L_{a+x}}{L_a}-\frac{2L_{x:a,c}}{L_{a,c}}\cdot\frac{L_{b+x}}{L_b}\right)$; and the assurance on the contingency may evidently bear the form in which Mr. BAILY has put it.

Example 9. On the death of the last survivor of A, B and C; provided that should be either A or B: this contingency in a similar manner from the proper interpretations of K″ and K‴, is found immediately $=-$ fluent of $\left(1-\overline{1-\frac{L_{b+x}}{L_b}}\cdot\overline{1-\frac{L_{c+x}}{L_c}}\cdot\frac{L_{a+x}}{L_a}+\overline{1-\frac{L_{a+x}}{L_a}}\cdot\overline{1-\frac{L_{c+x}}{L_c}}\cdot\frac{L_{b+x}}{L_b}\right)=-$ fluent of $\overline{1-\frac{L_{c+x}}{L_c}}\times\left(\overline{1-\frac{L_{b+x}}{L_b}}\cdot\frac{L_{a+x}}{L_a}+\overline{1-\frac{L_{a+x}}{L_a}}\cdot\frac{L_{b+x}}{L_b}\right)=$ fluent of $\overline{1-\frac{L_{c+x}}{L_c}}\cdot\left(\overline{1-\frac{L_{a+b}}{L_a}}\cdot=\overline{1-\frac{L_{c+x}}{L_c}}\cdot\overline{1-\frac{L_{b+x}}{L_b}}\cdot\overline{1-\frac{L_{c+x}}{L_c}}+$ fluent of $\frac{L_{c+x}}{L_c}\left(\overline{1-\frac{L_{b+x}}{L_b}}\cdot\overline{1-\frac{L_{a+x}}{L_a}}\right)$. Hence the assurance on this contingency, will be equal to the assurance on the longest of the three lives; — the assurance of C's life, provided that he be the last which fails. See Example 3. This in fact is almost evident at first sight.

Example 10. On the death of the first of the two A and B, provided it be the first or second which fails. This, as Mr. MORGAN, &c. observe, is on the extinction of the joint lives A and B only, &c.

Article 7. I shall now offer in the same order as in Mr. BAILY's work, some other questions of Mr. MORGAN's papers, which are most of them of a nature in point of solution different; in as much as that they contain in my method double fluents; or, as we have reduced them, contain fluents multiplied by variable quantities.

Example 1. The contingency of the first of the deaths of A and B, which shall be the second or third which happens of the three A, B and C, will be $-$ fluent of $\left(1-\frac{L_{c+z}}{L_c}\right)\left(\frac{L_{z:a,b}}{L_{a,b}}\right)^{\cdot}$ $+$ fluent of $\left(\frac{\dot{L}_{b+z}}{L_b}\right.$ fluent of $\left.\frac{L_{c+z}\cdot\dot{L}_{a+z}}{L_c\quad L_a}\right)+$ fluent of $\frac{\dot{L}_{a+z}}{L_a}$. fluent of $\frac{L_{c+z}\cdot\dot{L}_{b+z}}{L_c\cdot L_b}$. Since the first part is by Article 5, No. 2, of this Section; the contingency of the joint lives A and B failing after C, and the second by No. 5, denotes the chance of B's dying after the event has taken place of A's dying in the life time of C: and the third denotes the chance of A's dying after the event has taken place of B dying in the life time of A; and independent of the correction, the first part is evidently $=\frac{-L_{z:a,b}}{L_{a,b}}+$ fluent of $\frac{L_{c+z}\cdot\left(L_{a+z}\cdot L_{b+z}\right)^{\cdot}}{L_{a,b,c}}$; the second part is $=\frac{L_{b+z}}{L_b}$ fluent of $\frac{L_{c+z}\cdot\dot{L}_{a+z}}{L_{c,a}}-$ fluent of $\frac{L_{z:c,b}\cdot\dot{L}_{a+z}}{L_{a,b,c}}$ and the third part is equal to $\frac{L_{a+z}}{L_a}$ fluent of $\frac{L_{c+z}\cdot\dot{L}_{b+z}}{L_{c,b}}$ $-$ fluent of $\frac{L_{z:a,c}\cdot\dot{L}_{b+z}}{L_{a,b,c}}$; and the sum of the three or the contingency in question is independent of the correction

$= -\frac{L_{x:a,b}}{L_{a,b}} + \frac{L_{b+x}}{L_b}$, fluent of $\frac{L_{c+x}}{L_c}\cdot\frac{L_{a+x}}{L_a} + \frac{L_{a+x}}{L_a}$ fluent of $\frac{L_{c+x}\cdot L_{b+x}}{L_c\cdot L_b}$; and here it is evident, that when the lives are all equal, the contingency will become constant $-\frac{L_{x:a,a}}{L_{a,a}} + \frac{L_{a+x}}{L_a} \times$ constant $+ \left(\frac{L_{a+x}}{L_a}\right)^2$; or if all the fluents commence with $x=0$ it is $1 - \left(\frac{L_{a+x}}{L_a}\right)^2 - \frac{L_{a+x}}{L_a} + \left(\frac{L_{a+x}}{L_a}\right)^3$. But in other cases, if we are to have all the contingencies commence with $x=0$, and we are satisfied with the approximation that when two persons are dead, it is an equal chance which has died first, see note, Art. 2, Section 4, we shall have

$$\left.\begin{aligned}\frac{L_{b+x}}{L_b}\text{ fluent of }\frac{L_{c+x}}{L_c}\cdot\frac{L_{a+x}}{L_a} &= -\tfrac{1}{2}\frac{L_{b+x}}{L_b} + \tfrac{1}{3}\frac{L_{x:a,b}}{L_{a,b}} - \tfrac{1}{3}\frac{L_{x:b,c}}{L_{b,c}} + \tfrac{1}{3}\frac{L_{x:a,b,c}}{L_{a,b,c}}\\ \text{and }\frac{L_{a+x}}{L_a}\text{ fluent of }\frac{L_{c+x}\cdot L_{b+x}}{L_c\quad L_b} &= -\tfrac{1}{2}\frac{L_{a+x}}{L_a} + \tfrac{1}{2}\frac{L_{x:a,b}}{L_{a,b}} - \tfrac{1}{2}\frac{L_{x:a,c}}{L_{a,c}} + \tfrac{1}{2}\frac{L_{x:a,b,c}}{L_{a,b,c}}\end{aligned}\right\}$$

and therefore the whole becomes $= -\frac{1}{2}\frac{L_{b+x}}{L_b} - \frac{1}{2}\frac{L_{a+x}}{L_a} - \frac{1}{3}\frac{L_{x:b,c}}{L_{b,c}} - \frac{1}{2}\frac{L_{x:a,c}}{L_{a,c}} + \frac{L_{x:a,b,c}}{L_{a,b,c}} - 1$, and the part of the contingency due to the interval between the times π and $\pi+p$ is $\frac{L_{b+\pi} - L_{b+\pi+p}}{2L_b} + \frac{L_{a+\pi} - L_{a+\pi+p}}{L_a} + \frac{L_{\pi:b,c} - L_{\pi+p:b,c}}{2L_{b,c}} + \frac{L_{\pi:a,c} - L_{\pi+p:a,c}}{2L_{a,c}} - \frac{L_{\pi:a,b,c} - L_{\pi+p,a,b,c}}{L_{a,b,c}}$. Hence the assurance of one pound on the contingency, in case the event should happen between the times $n-p$ and m; to be paid at the first

of the equal periods p, from n—p, after the event, provided it be not beyond the time m is $\frac{1}{2}$. $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b + \frac{1}{2}\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a + \frac{1}{2}\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b, c + \frac{1}{2}\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, c - \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b, c$; that is half the sum of the assurances for the term on B's life, on A's life, on BC's joint life, and on AC's joint life;—the assurance on A, B, C's joint life for the term: on the supposition that if two persons are both to be dead, in a certain time less than their possible time of joint existence, it is an equal chance which is the survivor; our theorem therefore only goes to that term; after this, by consulting the formula, constant $-\frac{L_{x:a,b}}{L_{a,b}} + \frac{L_{b+x}}{L_b}$. fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a} + \frac{L_{a+x}}{L_a}$ fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}$; we find that if C be the one which must of necessity die before the extreme age of B or A; and if there is a possibility of his living as long as x is less than μ; we shall have $L_{c+\mu} = 0$: and the fluents of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a}$ and $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}$, after that time equal $-g$ and $-h$ if $-g$ and $-h$ be the values at that time; $\therefore$ after that time, the contingency, is constant $-\frac{L_{x:a,b}}{L_{a,b}} - g \cdot \frac{L_{b+x}}{L_a} - h \cdot \frac{L_{a+x}}{L_a}$; $\therefore$ if the whole assurance be required, find the whole value whilst m is not greater than μ, to which add $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b + g\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b + h\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b$.

But if A be the oldest, and there is a possibility of his living as long as x is less than μ, but not longer; use the theorem as long

as m is less than μ; if the whole assurance be required; and observing that when x is equal to, or greater than μ, that $\frac{L_{a+x}}{L_a}$. fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{L_{b+x}}{L_b}$ is $= o$; and that fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{L_{a+x}}{L_a}$ will be $= -g$; if $-g$ is its value when $x = \mu$, we shall find the contingency after that term, that is when x is greater than μ, $=$ constant $- g \frac{L_{b+x}}{L_b}$; and $\therefore$ the remainder of the assurance will be $= g \cdot \frac{\overset{x}{p}}{\underline{\quad}} \Big| b$ to be added. I do not state the case of B's being the oldest, because it is only necessary to write a for b in the last case to have this.

If we should not be satisfied with the approximation deduced, by assuming the equality of chance above named, during a long period, we have only to divide the period in shorter periods to attain any accuracy, being careful properly to correct the fluents.

The theorem I have just given for a solution to the problem in question, is so much more simple than the solutions I have seen to this problem, that I think it proper to inform the reader, that the cause will be understood from Art. 6, Section 3; and that no fear may be left in using the Theorem, I shall point out the connection between this solution and that given by Mr. BAILY, and I shall for the easier comparison denote L_a, L_b, L_c, by a, b, c; L_{a+x}, L_{b+x}, L_{c+x} by a', b', c'; and L_{a+x+1}, L_{b+x+1}, L_{c+x+1} by a'', b'', c''; and as the contingency, that the event takes place before the expiration of $n+1$, years will be found by writing n for x in the formula,

constant $-\frac{L_{x:\dot{a},b}}{L_{a,b}}+\frac{L_{b+x}}{L_b}$ fluent of $\frac{L_{c+x}}{L_c}\cdot\frac{L_{a+x}}{L_a}+\frac{L_{a+x}}{L_a}\times$ fluent of $\frac{L_{c+x}}{L_c}\cdot\frac{L_{b+x}}{L_b}$; we find this value under the idea of constant decrements for the whole term to be $1-\frac{a'b'}{ab}+\frac{b'}{b}$ $\cdot\left(-\frac{1}{2}\frac{bc}{ac}+\frac{1}{2}\frac{c.a'}{ac}-\frac{1}{2}\frac{\partial a}{ac}+\frac{1}{3}\frac{a'b'}{ac}\right)+\frac{a'}{a}\left(-\frac{1}{2}\frac{b_2}{bc}+\frac{1}{3}\frac{b^2_2}{bc}\right.$ $\left.-\frac{1}{2}\frac{c'_2}{bc}+\frac{1}{3}\frac{b'c'}{b.c}\right)=1+\frac{a'b'c'}{abc}-\frac{1}{2}\frac{b'}{b}-\frac{1}{2}\frac{a'}{a}-\frac{1}{2}\frac{b'c'}{bc}-\frac{1}{2}\frac{a'c'}{bc}$; and under the same hypothesis of the constant decrements, during the whole time $n+1$, we have the corresponding contingency $1+\frac{a''.b''.c'}{abc}-\frac{1}{2}\frac{b''}{b}-\frac{1}{2}\frac{a''}{a}-\frac{1}{2}\frac{b''c''}{bc}$ $-\frac{1}{2}\frac{a''c''}{bc}$; and the excess of this above the contingency for the term n, is $\frac{1}{2}\frac{b'-b''}{b}+\frac{1}{2}\frac{a'-a''}{a}+\frac{b'c'-b''c''}{2bc}+\frac{a'c'-a''c''}{2ac}-\frac{a'b'c'-a''b''c''}{2abc}$; the same except in notation as before, as it should be; the difference of the operation only being in the notation. But if we only consider the uniform decrements to reach to the period n, and then during the next year take proportional decrements during the year, we shall have the fluent of $\frac{L_{c+x}}{L}\cdot\frac{L_{a+x}}{L_a}$ answering to $x=n+1$, $=-\frac{1}{2}\frac{ac}{ac}+\frac{1}{2}\frac{ca'}{ac}-\frac{1}{2}\frac{a'c}{ac}$ $+\frac{1}{3}\frac{a'c'}{ac}-\frac{1}{2}\frac{a'c'}{ac}+\frac{a'a''}{2ac}$. See Art. 6, Section 3; consequently the value of $\frac{L_{b+x}}{L_b}$. fluent of $\frac{L_{c+x}}{L_c}\cdot\frac{L_{a+x}}{L_b}$ answering to $x=n+1$ is $=-\frac{1}{2}\frac{b'}{b}+\frac{1}{3}\frac{a'b'}{ab}-\frac{1}{2}\frac{c'b'}{bc}+\frac{1}{3}\frac{b'c'a''}{abc}-\frac{1}{2}\frac{a'b'c'}{abc}+\frac{a''b'c'}{2abc}$;

the corresponding value of $\frac{L_{a+x}}{L_a}$ fluent $\frac{L_{c+x}}{L_c}\cdot\frac{L_{b+x}}{L_b}$ will be

$= -\frac{1}{2}\frac{a''}{a} + \frac{1}{2}\frac{a''b'}{ab} - \frac{1}{2}\frac{c'a''}{ca} + \frac{1}{2}\frac{a''c'b''}{abc} - \frac{1}{2}\frac{a''b'c''}{abc} + \frac{a''b'c''}{2abc}$;

and the corresponding value of $\frac{L_{x:a,b}}{L_{a,b}} = \frac{a''b''}{ab}$. Hence we have the contingency on this hypothesis due to $n+1$ years $= 1 - \frac{a''b''}{ab} - \frac{1}{2}\frac{b''}{b} - \frac{1}{2}\frac{a''}{a} + \frac{1}{2}\frac{a'b''}{ab} + \frac{1}{2}\frac{a''b'}{ab} - \frac{1}{2}\frac{c'b''}{bc} - \frac{1}{2}\frac{c'a''}{ac} + \frac{a''b''c'}{abc} - \frac{a'b''c''}{2abc} - \frac{a''b'c''}{2abc} + \frac{a''b''c''}{abc}$; and if we take from this the chance of the events happening in n year, the remainder will be the chance of its happening during the interval between n and $n+1$ years; and will come out evidently $\frac{a'-a''}{2a} + \frac{b'-b''}{2b} + \frac{a'b''+a''b'-2a''b''}{2ab} + \frac{ab'-2a'b'+a'b-ab''-a''b+2a''b''}{2ab} \cdot \frac{c'}{c} - \frac{a'b''+a''b'-2a''b''}{2ab} \cdot \frac{c''}{c}$. And if we consider Mr. BAILY's a', b', c'; a'', b'', c'' to refer to the n^{th} and $n+1^{th}$ year, and collect his 1st, 2d, 3d, 5th, 6th, 8th, 9th, and 12th, contingencies, we shall find them amount to $\frac{a'-a''}{a}\left(\frac{1+b'}{2b} + \frac{c'}{c} \cdot \frac{1-b'-b''}{2b} - \frac{c''b''}{2bc}\right)$; and collecting the remaining terms which are 4th, 7th, 10th, 11th, and 13th, we obtain $\frac{b'-b''}{b}\left(\frac{a+a}{2a} + \frac{a-a'-a''}{2a} \cdot \frac{c'}{c} - \frac{a''c''}{ac}\right) - \frac{b'-b''}{b} \cdot \frac{a'-a''}{a}$; and if these two be added together we shall obtain the above expression.

Example 2. On the contingency of the first of the deaths of A and B, which shall be the first or last of the three A, B, C. This will evidently be the sum of the contingencies, of the joint lives discontinuing in C's life time; that A dies after B, C having died before B; and that B dies after A, C having died before A; therefore by Art 5 of this Section it is $= -$ fluent of $\frac{L_{c+z}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)$ + fluent of $\left(\frac{L_{d+z}}{L_a}\right.$ fluent of $\left.\left(1 - \frac{L_{c+z}}{L_c}\right)\right.$

$\frac{\dot{L}_{b+x}}{L_b}\Big) +$ fluent of $\Big(\frac{\dot{L}_{b+x}}{L_b}$ fluent of $\big(1 - \frac{L_{c+x}}{L_c}\big)\frac{\dot{L}_{a+x}}{L_a}\Big)$; but considering all the fluents to commence with $x = o$, the second term is $=$ fluent of $\Big(\frac{\dot{L}_{a+x}}{L_a} \times \Big(\frac{L-1}{L_{b+x}}$ — fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}\Big)\Big)$ and the third term is $=$ fluent of $\Big(\frac{\dot{L}_{b+x}}{L_b} \times \Big(\frac{L_{a+x}}{L_a} - 1$ — fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a}\Big)\Big)$, and therefore the sum of the two $=$ fluent of $\Big(\frac{L_{b+x}}{L_b} \cdot \frac{L_{a+x}}{L_a}\Big)$ — fluent of $\Big(\frac{\dot{L}_{a+x}}{L_a}$ fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}\Big)\Big)$ $+$ fluent of $\frac{\dot{L}_{b+x}}{L_b}$ fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}\Big) + 1 - \frac{L_{a+x}}{L_a}$ $+ 1 - \frac{L_{b+x}}{L_b}$; and the whole by comparison with the commencement of the last example; if the fluents are to be corrected in a similar manner to vanish with $x = o$ shows immediately that $1 - \frac{L_{a+x}}{L_a} + 1 - \frac{L_{b+x}}{L}$ — that value is equal to this; and therefore that the assurance of the contingency here, is the excess of the sum of the assurances on A's life and on B's life singly, above that: this agrees with the ingenious Mr. MILNE's observations on page 232 of his work on Assurances; and therefore, according to our solution of that case, we have during the possible joint existence the value $= \frac{1}{1} \cdot \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a + \frac{1}{2} \cdot \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b - \frac{1}{2} \cdot \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b, c - \frac{1}{2} \cdot \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, c + \overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b, c$, and

beyond that term the process as in the last example. This is according to the hypothesis of equality of chance, so often mentioned and used by Mr. MORGAN, &c.

Example 3. On the contingency of A's dying after C in the life time of A. This should come in the last article, as it does not involve the double fluent, but is given here not to interrupt the order in which I have taken my examples: the solution is $-$ fluent of $\frac{\dot{L}_{a+x}}{L_a} \cdot \overline{1 - \frac{L_{a+x}}{L_a} \cdot \frac{L_{b+x}}{L_b}}$, and is the chance of A's dying in the life time of B, $-$ the chance of A's dying in the life time of both A and B. Hence the assurances is determined from those cases, as Mr. BAILY has done page 273.

Example 4. On the contingency of A's dying last; on the condition that C dies before B. This will evidently be fluent of $\frac{\dot{L}_{a+x}}{L_a}$ (fluent of $(1 - \frac{L_{c+x}}{L_c}) \frac{\dot{L}_{b+x}}{L_b}$) $=$ if all the contingencies are supposed to commence with $x = o$, and the fluents be corrected to vanish with $x = o$, fluent of $\left(\frac{\dot{L}_{a+x}}{L_a} \frac{L_{b+x}}{L_b} - \frac{\dot{L}_{a+x}}{L_a} \right.$ $\left. - \frac{L_{a+x}}{L_a} \cdot \text{fluent of } \frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b} \right) = 1 - \frac{L_{a+x}}{L_a} +$ fluent of $\frac{\dot{L}_{a+x}}{L_a} \cdot \frac{L_{b+x}}{L_b} - \frac{L_{a+x}}{L_a}$ fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b} +$ fluent of $\frac{L_{x:a,c}}{L_{a,c}}$ $\cdot \frac{\dot{L}_{b+x}}{L_b}$; and the manner of obtaining each of these fluents has been already delivered; and thence may the assurances be determined. If we originally in the expression fluent of $\overline{1 - \frac{L_{c+x}}{L_c}}$

$\cdot \frac{\dot{L}_{b+x}}{L_b}$, which we will suppose to commence with x, write its approximate value $-\frac{1}{2}\left(1-\frac{L_{c+x}}{L_c}\,x\right)\left(1-\frac{L_{b+x}}{L_b}\right) = -\frac{1}{2} + \frac{1}{2}\frac{L_{c+x}}{L_c} + \frac{1}{2}\frac{L_{b+x}}{L_b} - \frac{1}{2}\frac{L_{c+x}}{L_c}\cdot\frac{L_{b+x}}{L_b}$; we get the contingency $= -\frac{1}{2}\left(\frac{L_{a+x}}{L_a}-1\right) + \frac{1}{2}$ fluent $\left(\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{a+x}}{L_a}\right) + \frac{1}{2}$ fluent of $\left(\frac{L_{b+x}}{L_b}\cdot\frac{L_{a+x}}{L_a}\right) - \frac{1}{2}$ fluent of $\frac{L_{c+x}\cdot L_{b+x}\cdot \dot{L}_{a+x}}{L_c \quad L_b \quad L_a}$ an approximation during the term of joint existence of B and C; and hence the method of finding the assurance for that term; for each part is evident from what has been shown; and how to proceed beyond that term, will be evident by considering the accurate fluent. But this last method throws the approximation on the whole value.

Example 5. On the death of A, provided he be the first or second of the three A, B, C; and provided C in the latter case dies before B. This contingency is $= -$ fluent of $\frac{\dot{L}_{a+x}}{L_a}\cdot\frac{L_{b+x}}{L_b}\cdot\frac{L_{c+x}}{L_c}$ — fluent of $\left(1-\frac{L_{c+x}}{L_c}\right)\cdot\frac{L_{b+x}}{L_b}\cdot\frac{\dot{L}_{a+x}}{L_a} = -$ fluent of $\left(\frac{L_{b+x}}{L_b}\cdot\frac{\dot{L}_{a+x}}{L_a}\right)$; and the assurance is the same as the assurance of A's death, on condition that he dies before B; as Messrs. MORGAN, &c. makes it. This does not contain the double fluent or the variable quantity multiplied by a fluent, and therefore may be considered out of its place.

Example 6. On the death of A, provided he be the 2d or 3rd that fails of the three A, B, C; and provided C dies be-

fore B; this is $=-$ fluent of $\left(\frac{\dot{L}_{a+x}}{L_a} \times \left\{(1-\frac{L_{c+x}}{L_c})\frac{L_{b+x}}{L_b}\right.\right.$ $\left.\left.-\text{fluent of } \overline{1-\frac{L_{c+x}}{L_c}\cdot\frac{L_{b+x}}{L_b}}\right\}\right) = \text{fluent of}\left(\frac{\dot{L}_{a+x}}{L_a}\right.$ (fluent of $\left.\left.\frac{L_{b+x}}{L_b}\cdot\frac{\dot{L}_{c+x}}{L_c}\right)\right) = \frac{L_{a+x}}{L_a}$ fluent of $\frac{L_{b+x}}{L_b}\cdot\frac{\dot{L}_{c+x}}{L_c}$ — fluent of $\frac{\dot{L}_{x:a,b}}{L_{a,b}}\cdot\frac{\dot{L}_{c+x}}{L_c}$, and each part has been already treated on.

Example 7. On the death of A, provided he be the first or last which fails of the three lives A, B, C; and provided C in the latter case dies before B. This is evidently $=-$ fluent of $\left(\frac{\dot{L}_{a+x}}{L_a}\left\{\frac{L_{x:b,c}}{L_c}-\text{fluent}\,(1-\frac{L_{c+x}}{L_c})\frac{\dot{L}_{b+x}}{L_b}\right\}\right) = -$ fluent of $\frac{\dot{L}_{a+x}}{L_a}\left\{\frac{L_{x:b,c}}{L_{b,c}}-\frac{L_{b+x}}{L_b}+1+\text{fluent of}\,\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}\right\} = 1-\frac{L_{a+x}}{L_a}$ $-$ fluent of $\left(\frac{L_{x:b,c}}{L_{b,c}}\cdot\frac{\dot{L}_{a+x}}{L_a}\right)+$ fluent of $\left(\frac{\dot{L}_{a+x}}{L_a}\cdot\frac{L_{b+x}}{L_b}\right)-\frac{L_{a+x}}{L_a}$. fluent of $\frac{\dot{L}_{c+x}}{L_c}\cdot\frac{L_{b+x}}{L_b}+$ fluent of $\frac{\dot{L}_{x:a,c}}{L_{a,c}}\cdot\frac{L_{b+x}}{L_b}$, and each part has been already considered.

Example 8. On the death of the longest of the two lives A and B, provided they be the first which fail of the three A, B and C; this is evidently fluent of $\left(\frac{L_{c+x}}{L_c}\times\left\{\overline{1-\frac{L_{a+x}}{L_a}}\right.\right.$ $\left.\left.\cdot\,1-\frac{L_{b+x}}{L_b}\right\}\right) = -$ fluent of $\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{a+x}}{L_a}-$ fluent of $\frac{L_{c+x}}{L_c}$ $\cdot\frac{\dot{L}_{b+x}}{L_b}+$ fluent of $\left(\frac{L_{a+x}}{L_a}\cdot\frac{L_{b+x}}{L_b}\right)\frac{L_{c+x}}{L_c}$; and the assurance

is the sum of the assurances on A if he survives C, and on B if he survives C — the assurance on C if he survives A or B. This agrees with Mr. BAILY's deduction. Note; for fluent of $\left(\frac{L_{a+x} \cdot L_{b+x}}{L_a \cdot L_b}\right) \frac{\dot{L}_{c+x}}{L_c}$ we may write $\frac{L_{x:a,b,c}}{L_{a,b,c}}$ — fluent of $\frac{L_{x:a,b}}{L_{a,b}} \cdot \frac{\dot{L}_{c+x}}{L_c}$, whence &c., and this not containing the fluent multiplied by a variable, may be considered out of its place.

Example 9. On the longest of the two lives A and B, provided they be the last that fail of the three A, B, C. This is fluent of $\left\{\frac{\dot{L}_{a+x}}{L_a}\right.$ fluent of $\overline{\left(1 - \frac{L_{c+x}}{L_c}\right)} \cdot \frac{\dot{L}_{b+x}}{L_b} + \frac{\dot{L}_{b+x}}{L_b}$ fluent of $\left.\overline{1 - \frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a}}\right\}$ = fluent of $\left\{\frac{\dot{L}_{a+x}}{L_a}\left(\frac{L_{b+x}}{L_b} - 1 - \text{fluent of } \frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}\right) + \frac{\dot{L}_{b+x}}{L_b}\left(\frac{L_{a+x}}{L_a} - 1 - \text{fluent of } \frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a}\right)\right\}$

= correction $- \frac{L_{a+x}}{L_a} - \frac{L_{b+x}}{L_b} + \frac{L_{x:a,b}}{L_{a,b}}$ — fluent of $\left(\frac{\dot{L}_{a+x}}{L_a} \cdot \text{fluent of} \frac{L_{a+x} \cdot \dot{L}_{b+x}}{L_{c,b}}\right)$ — fluent of $\left(\frac{\dot{L}_{b+x}}{L_b} \text{ fluent of } \frac{L_{c+x} \cdot \dot{L}_{a+x}}{L_c \cdot L_a}\right)$

= correction $- \frac{L_{a+x}}{L_a} - \frac{L_{b+x}}{L_b} + \frac{L_{x:a,b}}{L_{a,b}} - \frac{L_{a+x}}{L_a}$ fluent of $\left(\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}\right) - \frac{L_{b+x}}{L_b}$ (fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a}$) + fluent of $\frac{L_{c+x}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)$ and we may write for fluent of $\frac{L_{c+x}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)$ its equal $\frac{L_{x:a,b,c}}{L_{a,b,c}}$ — fluent of $\left(\frac{L_{x:a,b}}{L_{a,b}} \cdot \frac{\dot{L}_{x+c}}{L_c}\right)$ and each part, as

well as the assurance on each, has been already considered. But if we use immediately for the approximation of the fluents of $1-\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}$ and of $1-\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{a+x}}{L_a}$, when those contingencies are meant to commence when $x=0$, and not to last longer than the possible joint continuance of life, the approximations so often named, which are respectively $-\frac{1}{2}+\frac{1}{2}L_{b+x}+\frac{1}{2}L_{c+x}-\frac{1}{2}L_{x:b,c}$ and $-\frac{1}{2}+\frac{1}{2}L_{a+x}+\frac{1}{2}L_{c+x}-\frac{1}{2}L_{x:a,c}$ our formula, independent of the above reduction, will become fluent of $\left\{-\frac{\dot{L}_{a+x}}{2L_a}+\frac{L_{b+x}}{2L_b}\cdot\frac{\dot{L}_{a+x}}{2L_a}+\frac{1}{2}\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{a+x}}{L_a}-\frac{1}{2}\frac{L_{x:b,c}}{L_{b,c}}\cdot\frac{\dot{L}_{a+x}}{L_a}-\frac{\dot{L}_{b+x}}{2L_b}+\frac{L_{a+x}}{2L_a}\cdot\frac{\dot{L}_{b+x}}{L_b}+\frac{1}{2}\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}-\frac{1}{2}\frac{L_{x:a,c}}{L_{a,c}}\cdot\frac{\dot{L}_{b+x}}{L_x}\right\}$ = correction $-\frac{1}{2}\frac{L_{a+x}}{L_a}-\frac{1}{2}\frac{L_{b+x}}{2L_b}+\frac{1}{2}\frac{L_{x:a,b}}{L_{a,b}}+\frac{1}{2}$ fluent of $\left(\frac{L_{c+x}}{L_c}\cdot\frac{L_{a+x}}{L_a}\right)+\frac{1}{2}$ fluent of $\left(\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}\right)-\frac{1}{2}$ fluent of $\frac{L_{x+c}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)$. But this last method throws the approximation on the whole term.

I may observe that the first method will resolve itself into correction $-\frac{L_{a+x}}{L_a}-\frac{L_{b+x}}{L_b}+$ fluent of $\left(\frac{L_{c+x}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)\right)$ — contingency of Example 1 Art. 7 of this Section, and the assurance will in consequence be the assurances on the single lives A and B together;—the assurance of that Example;—the assurance on the three joint lives A, B, C; +the assurance of C's life provided it fails before A and B. The last two

expressions of this formula are derived from the resolution of fluent of $\frac{L_{c+x}}{L_c}\left(\frac{L_{x:a,b}}{L_{a,b}}\right)$ into $\frac{L_{x:a,b,c}}{L_{a,b,c}}$ — fluent of $\frac{L_{x:a,b}}{L_{a,b}} \cdot \frac{\dot{L}_{c+x}}{L_c}$.

Example 10. On the death of the longest of the lives A and B; provided they be the first and last of the three A B and C. This is fluent of $\left\{\frac{\dot{L}_{a+x}}{L_a}\right.$ fluent of $\left(1 - \frac{L_{b+x}}{L_b} \cdot \frac{\dot{L}_{c+x}}{L_c}\right) +$ $\frac{\dot{L}_{b+x}}{L_b}$ fluent of $\left.\left(1 - \frac{L_{a+x}}{L_a}\frac{\dot{L}_{c+x}}{L_c}\right)\right\}$ = fluent of $\frac{\dot{L}_{a+x}}{L_a}\left(\frac{L_{c+x}}{L_c}\right.$ $\left. - 1 - \text{fluent of } \frac{L_{b+x}}{L_b} \cdot \frac{\dot{L}_{c+x}}{L_c}\right) +$ fluent of $\frac{\dot{L}_{b+x}}{L_b}\left(\frac{L_{c+x}}{L_c} - 1\right.$ $\left. - \text{fluent of } \frac{L_{a+x}}{L_a} \cdot \frac{\dot{L}_{c+x}}{L_c}\right)$ = correction $- \frac{L_{a+x}}{L_a} - \frac{L_{b+x}}{L_b} +$ fluent of $\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+x}}{L_a}$ + fluent of $\frac{\dot{L}_{c+x}}{L_c} \cdot \frac{L_{b+x}}{L_b} - \frac{L_{a+x}}{L_a}$ fluent of $\frac{L_{b+x}}{L_b} \cdot \frac{\dot{L}_{c+x}}{L_c} - \frac{L_{b+x}}{L_b}$ fluent of $\frac{L_{a+x}}{L_a} \cdot \frac{\dot{L}_{c+x}}{L_c} - 2$ fluent of $\frac{L_{x:a,b}}{L_{a,b}} \cdot \frac{\dot{L}_{c+x}}{L_c}$.

Example 11. On the death of the longest of the lives A and B; provided B dies before C. This is fluent of $\left(\frac{\dot{L}_{a+x}}{L_a}\right.$ $\left.\left(\text{fluent of } \frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{a+b}}{L_a}\right)\right) - \text{fluent of } \frac{\dot{L}_{b+x}}{L_b}\left(1 - \frac{L_{a+x}}{L_a}\right)\frac{L_{c+x}}{L_c}$ $= \frac{L_{a+x}}{L_a}$ fluent of $\left(\frac{L_{c+x}}{L_c} \cdot \frac{\dot{L}_{b+x}}{L_b}\right) - \text{fluent of } \frac{L_{x:a,c}}{L_{a,c}} \cdot \frac{\dot{L}_{b+x}}{L_b}\Big)$

$$-\text{fluent of } \frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b} + \text{fluent of } \frac{L_{a:a,c}}{L_{a,c}}\cdot\frac{\dot{L}_{b+x}}{L_b} = \frac{L_{a+x}}{L_a}$$

$$\cdot\,\text{fluent of}\left(\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}\right) - \text{fluent of } \frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}.$$

Note. This result may be obtained in rather a more simple manner; for the chance depends on the two events; namely, that A shall be dead, and that B dies whilst C is living; the former is $1-\frac{L_{a+x}}{L_a}$; and the latter is $-\text{fluent of } \frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}$ and the rectangle of the two gives the expression above.

Example 12. On the death of A and B, provided another life C, dies before B. This is fluent of $\left(\frac{L_{a+x}}{L_a}\right.$ fluent of $\left(1-\frac{L_{c+x}}{L_c}\right.$

$$\left.\left.\cdot\frac{\dot{L}_{b+x}}{L_b}\right) - \text{fluent}\frac{\dot{L}_{b+x}}{L_b}\cdot\overline{1-\frac{L_{a+x}}{L_a}}\cdot\overline{1-\frac{L_{c+x}}{L_c}} = \frac{L_{a+x}}{L_a}\,\text{fluent of}\right.$$

$$\left(1-\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}\right) - \text{fluent of } \left(1-\overline{1-\frac{L_{c+x}}{L_c}}\cdot\frac{L_{a+x}}{L_a}\cdot\frac{\dot{L}_{b+x}}{L_b}\right)$$

$$-\text{fluent of } \frac{\dot{L}_{b+x}}{L_b}\cdot\overline{1-\frac{L_{a+x}}{L_a}}\cdot\overline{1-\frac{L_{b+x}}{L_c}} = 1+\frac{L_{a+x}}{L_a}\cdot\frac{L_{b+x}}{L_b}$$

$$-\frac{L_{a+x}}{L_a}-\frac{L_{a+x}}{L_a}\,\text{fluent of}\,\frac{L_{c+x}}{L_c}\cdot\frac{\dot{L}_{b+x}}{L_b}-\frac{L_{b+x}}{L_b}+\text{fluent}\,\frac{L_{c+x}}{L_c}$$

$$\cdot\frac{\dot{L}_{b+x}}{L_b}.$$ If the contingencies begin with x.

There are some observations to be made on the manner we have corrected the fluents; and also on the manner of calculating without the usual tables, for which consult the Scholium.

Scholium.

As the Tables calculated for the valuation of annuities or yearly incomes may be serviceable for the valuation of incomes payable at less periods, it will be proper to show how the value of such incomes depend on each other; and also to show how to compare the value of assurances on lives, when the sum assured is to be received at some one of a number of periods which is to happen after the death, reckoning from a fixed period, with the value of the assurance, if the sum is to be received at a given distant time from the death; for instance, what is commonly called the assurance of £1. on a life, is the value of one pound to be received at the first anniversary from the payment of the premium, which shall happen after the death; but it is not the value of one pound to be received at the death; and it is, as will appear farther on, very nearly the value of one pound to be received a half year after the death shall happen.

Art. 1. Problem. Given $\overset{r}{\underset{m}{\overset{p}{n}}}|a, b, c, \&c.$ to find $\overset{r}{\underset{m}{\overset{q}{n}}}|a, b, c, \&c. \times \frac{q}{p}$ nearly, $\frac{p}{q}$ being a whole number, and p a small period?

Solution. We shall have $\overset{r}{\underset{m}{\overset{q}{n}}}|a, b, c, \&c. = \overset{r}{\underset{n+p-q}{\overset{q}{n}}}|a, b, c, \&c. +$

$$\overset{s}{\underset{n+2p-q}{\overset{q}{n+p}}}|a, b, c, \&c. + \overset{r}{\underset{n+3p-q}{\overset{q}{n+2p}}}|a, b, c, \&c. \ldots\ldots \overset{r}{\underset{m-q}{\overset{q}{m-p}}}|a, b, c, \&c. +$$

$r^m \cdot \frac{L_{m:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$. But considering that during the whole of

any small interval p, that the living corresponding to time which are in arithmetical progression, are in geometrical progression. (See Section 3, Art. 2), $\overset{r}{\underset{\varpi+p-q}{\overset{q}{\varpi}}}\Big|_{a,\,b,\,c,\,\&c.}$ will be $= r^{\varpi} \cdot \frac{L_{\varpi:\,a,\,b,\,c,\,\&c.}}{L_{a,\,b,\,c,\,\&c.}} \times \frac{1-r^{p} \cdot \frac{L_{\varpi+p:\,a,\,b,\,c,\,\&c.}}{L_{\varpi:\,a,\,b,\,c,\,\&c.}}}{1-r^{q} \cdot \frac{L_{\varpi+q:\,a,\,b,\,c,\,\&c.}}{L_{\varpi:\,a,\,b,\,c,\,\&c.}}}$; but by the hypothesis $\overline{\frac{L_{\varpi+q:\,a,\,b,\,c,\,\&c.}}{L_{\varpi:\,a,\,b,\,c}}}^{\frac{p}{q}} = \frac{L_{\varpi+p:\,a,\,b,\,c,\,\&c.}}{L_{\varpi:\,a,\,b,\,c,\,\&c.}}$; consequently, if we put $r^{p} \cdot \frac{L_{\varpi+p:\,a,\,b,\,c,\,\&c.}}{L_{\varpi:\,a,\,b,\,c,\,\&c.}} = 1-k$, we shall have $\overset{r}{\underset{\varpi+p-q}{\overset{q}{\varpi}}}\Big|_{a,\,b,\,c,\,\&c.}$ $= r^{\varpi} \cdot \frac{L_{\varpi:\,a,\,b,\,c,\,\&c.}}{L_{\varpi:\,a,\,b,\,c,\,\&c.}} \times \frac{1-k}{1-(1-k)^{\frac{q}{p}}}$. Here k is generally very small; and if in the developement of $\overline{1-k}^{\frac{q}{p}}$, we are satisfied with retaining only the first and second powers of k, we shall have $\overset{r}{\underset{\varpi+p-q}{\overset{q}{\varpi}}}\Big|_{a,\,b,\,c,\,\&c.} = r^{\varpi} \cdot \frac{L_{\varpi:\,a,\,b,\,c,\,\&c.}}{L_{a,\,b,\,c,\,\&c.}} \times \frac{1}{\frac{q-q}{p}\,\frac{p}{p}\,\frac{q-p}{2p} \cdot k} = \frac{p}{q} \cdot r^{\varpi} \cdot \frac{L_{\varpi:\,a,\,b,\,c,\,\&c.}}{L_{a,\,b,\,c,\,\&c.}} \times \left(1 - \frac{p-q}{2p} \cdot k\right)$ nearly; $= \frac{p}{q} r^{\varpi} \cdot \frac{L_{\varpi:\,a,\,b,\,c,\,\&c.}}{L_{a,\,b,\,c,\,\&c.}} \times \left(\frac{p+q}{2p} + \frac{p-q}{2p} \cdot \overline{1-k}\right) = \frac{p+q}{2q} r^{\varpi} \cdot \frac{L_{\varpi:\,a,\,b,\,c,\,\&c.}}{L_{a,\,b,\,c,\,\&c.}} + \frac{p-q}{2q} \cdot r^{\varpi+p} \cdot \frac{L_{\varpi+p:\,a,\,b,\,c,\,\&c.}}{L_{a,\,b,\,c,\,\&c.}}$. Hence, if we interpret ϖ successively by n, $n+p$, $n+2p$, &c. $m-p$, we shall get as an approximation from the above value of $\overset{r}{\underset{m}{\overset{q}{n}}}\Big|_{a,\,b,\,c,\,\&c.}$, $\overset{r}{\underset{m}{\overset{q}{n}}}\Big|_{a,\,b,\,c,\,\&c.} \cdot \frac{q}{p} = \left(\frac{p+q}{2p}\right.$

$$\cdot r^{n} \cdot \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c,\&c.}} + \frac{\overbrace{p-q}}{2p} \cdot r^{n+p} \cdot \frac{L_{n+p:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \Big) + \Big(\frac{\overbrace{p+q}}{2p} \cdot r^{n+p} \cdot L_{n+p:a,b,c,\&c.}$$

$$+ \frac{\overbrace{p-q}}{2p} r^{n+2p} \cdot \frac{L_{n+2p:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \Big) \ldots\ldots \Big(\frac{\overbrace{p+q}}{2p} r^{m-p} \cdot \frac{L_{m-p:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$$

$$+ \frac{\overbrace{p-q}}{2p} \cdot r^{m} \cdot \frac{L_{m:a,b,c,\&c.}}{L_{a,b,c,\&c.}} \Big) + \frac{p}{q} \cdot \frac{L_{m:a,b,c,\&c.}}{L_{a,b,c,\&c.}} = \frac{\overbrace{p+q}}{2p} \cdot r^{n} \cdot \frac{L_{n:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$$

$$+ \frac{1}{L_{a,b,c,\&c.}} \times \big(r^{n+p} \cdot L_{n+p:a,b,c,\&c.} + r^{n+2p} \cdot L_{n+2p:a,b,c,\&c.}$$

$$\ldots\ldots + r^{m} \cdot L_{m:a,b,c,\&c.} \big) - r^{m} \cdot \frac{\overbrace{p-q}}{2p} \cdot \frac{L_{m:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$$

$$= \frac{r^{n} \cdot \overbrace{p+q} \cdot L_{n:a,b,c,\&c.} - r^{m} \cdot \overbrace{p-q} \cdot L_{m:a,b,c,\&c.}}{2p \cdot L_{a,b,c,\&c.}} + \overbrace{\underset{m}{\overset{p}{\underset{\overset{r}{n+p}}{|}}}}\underline{a,b,c,\&c.}, \text{ or}$$

$$= - \frac{\overbrace{p-q}}{2p L_{a,b,c,\&c.}} \left(r^{n} \cdot L_{n:a,b,c,\&c.} + r^{m} L_{m:a,b,c,\&c.} \right) + \overbrace{\underset{m}{\overset{p}{|}}}\underline{a,b,c}$$

As a particular example, if we take $n=0$, m infinite, $p=1$, $q=\frac{1}{2}$, we have $\overbrace{\underset{0}{\overset{r}{\frac{1}{2}}}|}\underline{a,b,c.} \cdot \frac{1}{2} = \frac{1}{4} + \overbrace{\underset{1}{\overset{r}{1}|}}\underline{a,b,c,\&c.}$ nearly, and therefore $\overbrace{\underset{\frac{1}{2}}{\overset{r}{\frac{1}{2}}|}}\underline{a,b,c,\&c.} \cdot \frac{1}{2} =$ nearly $\frac{1}{4} - \frac{1}{2} r^{\frac{1}{2}} \frac{L_{\frac{1}{2}:a,b,c}}{L_{a,b,c}} + \overbrace{\underset{1}{\overset{r}{1}|}}\underline{a,b,c,\&c.}$; (or because $r^{\frac{1}{2}} \frac{L_{\frac{1}{2}:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$ differs but little from unity) nearly equal to $\frac{1}{4} + \overbrace{\underset{1}{\overset{r}{1}|}}\underline{a,b,c,\&c.}$: that is an income of half a pound payable half yearly on the joint lives of the ages a, b, c, &c. is nearly equal to $\frac{1}{4}$ of a pound + the life annuity of one pound on the same lives. If $q=\frac{1}{4}$ we have $\overbrace{\underset{0}{\overset{r}{\frac{1}{4}}|}}\underline{a,b,c,\&c.} \cdot \frac{1}{4} = \frac{1}{8} + \overbrace{\underset{1}{\overset{r}{1}|}}\underline{a,b,c,\&c.}$ nearly; and $\overbrace{\underset{\frac{1}{4}}{\overset{r}{\frac{1}{4}}|}}\underline{a,b,c,\&c.} \cdot \frac{1}{4} = \frac{1}{8} - \frac{1}{4} r^{\frac{1}{4}} \cdot \frac{L_{\frac{1}{4}:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$

$+ {}^{r}_{1}\big|_{1}\underline{a, b, c, \&c.} = \frac{1}{2} + {}^{r}_{1}\big|_{1}\underline{a, b, c, \&c.}$ nearly; and similarly is ${}^{r}_{0}\big|_{0}\underline{a, b, c, \&c.}$

$. 0 = \frac{1}{2} + {}^{r}_{1}\big|_{1}\underline{a, b, c, \&c.}$ nearly; that is a momentary income, which in a year certain without interest would amount to one pound, will, if it is to be received on the joint lives a, b, c, &c. reckoning interest, be worth $\frac{1}{2}$ + the life annuity of one pound payable on the joint lives a, b, c, &c.

Art. 2. Moreover, because (Art. 3, Section 1) ${}^{r}_{n}\big|_{m}\underline{a, b, c, \&c.}$

$= {}^{r}_{n-q}\big|_{m-q}\underline{a, b, c, \&c.} \cdot r^{q} - {}^{r}_{n}\big|_{m}\underline{a, b, c, \&c.} = {}^{r}_{n}\big|_{m}\underline{a, b, c, \&c.} \cdot r^{q} + r^{n} \cdot \frac{L_{n-q:\, a, b, c, \&c.}}{L_{a, b, c, \&c.}}$

$- r^{m+q} \cdot \frac{L_{m:\, a, b, c, \&c.}}{L_{a, b, c, \&c.}} - {}^{r}_{n}\big|_{m}\underline{a, b, c, \&c.} = r^{n} \cdot \frac{L_{n-q:\, a, b, c, \&c.} - r^{m+q} \cdot L_{m:\, a, b, c, \&c.}}{L_{a, b, c, \&c.}}$

$-(1-r^{q}) \times {}^{r}_{n}\big|_{m}\underline{a, b, c, \&c.}$, it is therefore from above =

$$r^{n} \cdot \frac{L_{n-q:\, a, b, c, \&c.} - r^{m+q} \cdot L_{m+q:\, a, b, c, \&c.}}{L_{a, b, c, \&c.}} - (1-r^{q}) \frac{p}{q} \left\{ \frac{r^{n} \cdot \overline{p+q} \cdot L_{n:\, a, b, c, \&c.} - r^{m+q} \cdot \overline{p-q}\, L_{m:\, a, b, c, \&c.}}{2p \cdot L_{a, b, c, \&c.}} \right.$$

$\left. + {}^{r}_{n+p}\big|_{m}\underline{a, b, c, \&c.} \right\}$. If $p=1$, $q=0$, $n=0$, m infinite, since $1-r^{1}$ will be equal to q hyp. log. of $\frac{1}{r}$ we shall have ${}^{r}_{0}\big|_{0}\underline{a, b, c, \&c.} =$ nearly $1-\frac{1}{2}$ hyp. log. of $\frac{1}{r}$ — hyp. log. of $\frac{1}{r} \times {}^{r}_{1}\big|_{1}\underline{a, b, c, \&c.}$; and if for — hyp. log. of $\frac{1}{r}$ or its equal hyp. log. of $1-(1-r)$ we write $-(1-r) - \frac{(1-r)^{2}}{2} - \frac{(1-r)^{3}}{3}$, &c. the expression will

evidently, since r is near unity, be nearly equal to $1 - \frac{1-r}{2} - (1-r) \cdot 1 + \left(\frac{1-r}{2}\right)^2 \cdot \overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.}$ = nearly $r^{\frac{1}{2}} - \frac{1-r}{r^{\frac{1}{2}}} \cdot \overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.}$ but $\overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.} = r - (1-r) \overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.}$; $\therefore \cdot \overset{r}{\underset{0}{0}}|\underline{a, b, c, \&c.} = \frac{1}{r^{\frac{1}{2}}} \times \overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.}$ nearly ; that is the value of one pound to be received at the discontinuance of the joint lives of the ages a, b, c, &c. is equal nearly to $\frac{1}{r^{\frac{1}{2}}}$ × the value of one pound to be received at the first anniversary from the present time, which shall happen after the discontinuance of the same lives. Also $\overset{r}{\underset{0}{0}}|\underline{a, b, c, \&c.} \cdot r^{\frac{1}{2}}$ or which is the same thing, the value of one pound to be received a half year after the discontinuance of the joint lives is nearly $= \overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.}$, or the value of one pound to be received at the first anniversary from the present time, which shall happen after the discontinuance of the joint lives; and $\overset{r}{\underset{0}{0}}|\underline{a, b, c, \&c.} \cdot r$ is nearly $= \overset{r}{\underset{1}{1}}|\underline{a, b, c, \&c.} \cdot r^{\frac{1}{2}}$; that is the value of one pound to be received one year after the discontinuance of the joint lives of the ages a, b, c, &c. is nearly equal to $r^{\frac{1}{2}}$ × the value of the same contingency on one pound to be received at the first anniversary which shall happen after the discontinuance of the joint lives.

Art. 3. Again with respect to the calculation of the value of the expresion $\frac{L_{b-q}}{L_b} \cdot \overset{r}{\underset{m}{\overset{q}{n}}}|\underline{a, b-q} - \frac{L_{a-q}}{L_a} \cdot \overset{r}{\underset{m}{\overset{q}{n}}}|\underline{b, a-q}$ from the

value of the expression $\frac{L_{b-p}}{L_b} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,\,b-p} - \frac{L_{a-p}}{L_a} \cdot \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a-p,\,b}$, and the like; see Art. 3. Section 4. I observe if $\frac{p}{q}$ be a whole number, and p small, from Art. 1 of this Scholium, that $\overset{r}{\underset{m}{\overset{q}{n}}}\Big|_{g,\,b}$ $= -\frac{p-q}{2q} \cdot \frac{r^n \cdot L_{n:\,g,\,b} + r^m L_{m:\,g,\,b}}{L_{g,\,b}} + \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{g,\,b} \cdot \frac{p}{q}$; therefore $\frac{L_{b-q}}{L_b}$ $\cdot \overset{r}{\underset{m}{\overset{q}{n}}}\Big|_{a,\,b-q} - \frac{L_{a-q}}{L_a} \cdot \overset{r}{\underset{m}{\overset{q}{n}}}\Big|_{b,\,a-q} = -\frac{p-q}{2q\,L_{a,\,b}} \cdot (r^n \cdot L_{n:\,a,\,b-q} +$ $r^m \cdot L_{m:\,a,\,b-q} - r^n \cdot L_{n:\,a-q,\,b} - r^m \cdot L_{m:\,a-q,\,b}) + \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,\,b-q}$ $\cdot \frac{L_{b-q}}{L_b} \cdot \frac{p}{q} - \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a-q,\,b} \cdot \frac{L_{a-q}}{L_a} \cdot \frac{p}{q}$. But $L_{n:\,a,\,b-q} - L_{n:\,b,\,a-q} =$ $L_{n+a} \times (L_{n+b} + \frac{q}{p}(L_{n+b-p} - L_{n+b})) - L_{n+b} \times (L_{n+a} +$ $\frac{q}{p}(L_{n+a-p} - L_{n+a}))$ nearly under the hypothesis of q and p being small intervals; and this by an evident reduction is simply $\frac{q}{p}(L_{n:\,a,\,b-p} - L_{n:\,b,\,a-p})$; and in the same way it is shown that $L_{n:\,a,\,b-q} - L_{n:\,b,\,a-q} = \frac{q}{p}(L_{n:\,a,\,b-p} - L_{n:\,b,\,a-p})$ nearly. Moreover $\overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a,\,b-q} \cdot \frac{L_{b-q}}{L_b} - \overset{r}{\underset{m}{\overset{p}{n}}}\Big|_{a-q,\,b} \cdot \frac{L_{a-q}}{L_a} =$ $r^n \cdot \frac{L_{n:\,a,\,b-q} - L_{n:\,b,\,a-q}}{L_{a,\,b}} + r^{n+p} \cdot \frac{L_{n+p:\,a,\,b-q} - L_{n+p:\,a-q,\,b}}{L_{a,\,b}} +$ &c. $=$ from above, nearly $\frac{q}{p}\left\{r^n \cdot \frac{L_{n:\,a,\,b-q} - L_{n:\,b,\,a-p}}{L_{a,\,b}} + \right.$

$$r^{n+p}\cdot\frac{L_{n+p:a,b-p}-L_{n+p:b,a-p}}{L_{a,b}}+\&c.\Big\}=\frac{1}{s^p}\Big\{\frac{L_{b-p}}{L_b}\cdot\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a,b-p$$

$$-\frac{L_{a-p}}{L_a}\cdot\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b,a-p\Big\}.\quad\text{Hence we get}\quad\frac{L_{b-q}}{L_b}\cdot\overset{r}{\underset{m}{\overset{q}{\underset{n}{|}}}}a,b-q-\frac{L_{a-q}}{L_a}$$

$$\cdot\overset{r}{\underset{m}{\overset{q}{\underset{n}{|}}}}b,a-q=\text{nearly}-\frac{p-q}{sp}\cdot\frac{r^n\cdot(L_{n:a,b-p}-L_{n:b,a-p})+r^m\cdot(L_{m:a,b-p}-L_{m:b,a-p})}{L_{a,b}}$$

$$+\frac{L_{b-p}}{L_b}\cdot\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a,b-p-\frac{L_{a-p}}{L_a}\cdot\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}b,a-p,\ \text{when}\ \frac{p}{q}\ \text{is a whole}$$

number.

Article 4. It is proper to observe, that what refers to the fluents of the expressions $L_{q+x}\times\dot{L}_{r+x}$, $L_{p+x}\times L_{s+x}\times\dot{L}_{r+x}$, &c. of Section 3, equally apply whether L in the different expressions L_{q+x}, L_{r+x}, &c. is, *mutatis mutandis*, the same, or a different functional characteristic, whether when they refer to life contingencies, if L in the one part refers to one given constitution, and in the other part it refers to another constitution or not; for instance, if in the expression $L_{q+x}\times\dot{L}_{r+x}$, L_{q+x} refers to the Northampton lives, and L_{r+x} to the Swedish lives, or whether they both refer to the same lives, &c. Whether they refer to the number of living at the ages $q+x$ and $r+x$, or whether they refer with respect to the variable time x to expressions compounded of the number of living and dead. But instead of resuming the characteristic L here, I shall, with a view to better distinction, consider the value

$\overset{x}{\underset{w}{\overset{0}{|}}}M_x\dot{N}_x$. And I observe, similarly to what is done in Sec-

tion 3, that if x be put $= r + t$, and that if when t be not greater than p, M_{r+t} be equal to $M_r - tM'_r$, and $N_{r+t} = N_r - tN'_r$ sufficiently near, that we shall have $\overline{\begin{smallmatrix} o \\ r \\ r+p \end{smallmatrix}} M_x . N_x =$ $\overline{\begin{smallmatrix} i \\ o \\ o \\ p \end{smallmatrix}} M_{r+t} \times N_{r+t} = \overline{\begin{smallmatrix} i \\ o \\ o \\ p \end{smallmatrix}} \overline{M_r - M'_r t} \times (-N' i) = -pN'_r M_r$ $+ \frac{p^2}{2} . M'_r N'_r = -pN'_r \times \overline{M_r - \frac{p}{2} M'_r} = -pN'_r . M_{r+\frac{p}{2}}$ $= -(N_r - N_{r+p}) M_{r+\frac{p}{2}}$. And therefore if M_x represent the chance that a certain circumstance shall exist at the time x, and N_x the chance that some other certain object shall exist at the time x; then the chance that the second circumstance shall fail during the existence of the first between the time $n-p$ and m is sufficiently nearly $= \overline{\begin{smallmatrix} r \\ n \to p \\ m-p \end{smallmatrix}} (\overline{N_r - N_{r+p}} \times M_{r+\frac{1}{2}p})$. And the present value of one pound to be received at the first of the periods $n, n+p, n+2p$, &c. from the present time, which shall happen after such failure, provided it shall take place between the time $n-p$ and m, will be according to hypothesis with sufficient proximity $= \overline{\begin{smallmatrix} r \\ n \to p \\ m-p \end{smallmatrix}} (r^{r+p} \times \overline{N_r - N_{r+p}}$ $\times M_{r+\frac{p}{2}}) = \overline{\begin{smallmatrix} r \\ n \to p \\ m-p \end{smallmatrix}} (r^{r+p} \times N_r . M_{r+\frac{p}{2}}) - \overline{\begin{smallmatrix} r \\ n \to p \\ m-p \end{smallmatrix}} (r^{r+p} \times N_{r+p} \times$ $M_{r+\frac{p}{2}})$. And this mode of investigation will afford different modes of solution to ALL THE EXAMPLES OF SECTION 4. For instance: if this be applied to Example 8, Art. 7, Section 4, by

taking $N_x = \left(1 - \frac{L_{a+x}}{L_a}\right) . \left(1 - \frac{L_{b+x}}{L_b}\right)$ and $M_x = \frac{L_{c+x}}{L_c}$, the assurance of one pound on the contingency of that example will become $\overline{\left.\begin{matrix}\overline{p}\\ n-p\\ m-p\end{matrix}\right|} \left(r^{x+p} . \left(1 - \frac{L_{a+x}}{L_a}\right) . \left(1 - \frac{L_{b+x}}{L_b}\right) . \frac{L_{c+x+\frac{1}{2}p}}{L_c}\right)$ $- \overline{\left.\begin{matrix}\overline{p}\\ n-p\\ m-p\end{matrix}\right|} \left(r^{x+p} . \left(1 - \frac{L_{a+x+p}}{L_a}\right) . \left(1 - \frac{L_{b+x+p}}{L_b}\right) . \frac{L_{c+x+\frac{1}{2}p}}{L_c}\right) =$ $r^p . \frac{L_{c+\frac{1}{2}p}}{L_c}$ × the income of one pound payable at every p interval, the first in the time $n-p$, and the last in the time $m-p$ on the life of the age $c + \frac{1}{2}p$, after the death of the two persons of the ages a and b, — $\frac{L_{c-\frac{1}{2}p}}{L_c}$ × the income of one pound payable at every p interval, the first in the time n, and the last in the time m on the life of the age $c - \frac{1}{2}p$, after the death of the ages a and b. " Because the first term of these two expressions is $r^p . \frac{L_{c+\frac{1}{2}p}}{L_c} \times \overline{\left.\begin{matrix}\overline{p}\\ n-p\\ m-p\end{matrix}\right|} \left(r^x . 1 - \frac{L_{a+x}}{L_a} . 1 - \frac{L_{b+x}}{L_b} . \frac{L_{a+x+\frac{1}{2}p}}{L_{c+\frac{1}{2}p}}\right)$ " $= \overline{\left.\begin{matrix}\overline{p}\\ n-p\\ m-p\end{matrix}\right|} \left(r^{x+p} . 1 - \frac{L_{a+x}}{L_a} . 1 - \frac{L_{b+x}}{L_b} . \frac{L_{c+x+\frac{1}{2}p}}{L_c}\right)$ and the " second term of the expression is $= \frac{L_{c+\frac{1}{2}p}}{L_c} \times \overline{\left.\begin{matrix}\overline{p}\\ n\\ m\end{matrix}\right|} \left(r^n . 1 - \frac{L_{a+x}}{L_a} . 1 - \frac{L_{b+x}}{L_b} . \frac{L_{c+x-\frac{1}{2}p}}{L_{c-\frac{1}{2}p}}\right) = \overline{\left.\begin{matrix}\overline{p}\\ n-p\\ m-p\end{matrix}\right|} \left(r^{x+p} . 1 - \frac{L_{a+x+p}}{L_a} . 1 - \frac{L_{b+x+p}}{L_b} . \frac{L_{c+x+\frac{1}{2}p}}{L_c}\right)$." Or we may develope the expression in the form

$$\overbrace{\begin{matrix}p\\n-p\\m-p\end{matrix}}^{w}\Big|\left(\left(r^{w+p}\times\frac{L_{w:a,b,c+\frac{1}{2}p}}{L_{a,b,c}}-\frac{L_{w+p:a,b,c-\frac{1}{2}p}}{L_{a,b,c}}-\frac{L_{w:a,c+\frac{1}{2}p}}{L_{a,c}}-\frac{L_{w:b,c+\frac{1}{2}p}}{L_{b,c}}+\frac{L_{w+p:a,c-\frac{1}{2}p}}{L_{a,c}}+\frac{L_{w+p:b,c-\frac{1}{2}p}}{L_{b,c}}\right)\right)=r^{p}\cdot\frac{L_{c+\frac{1}{2}p}}{L_{c}}\times$$

$$\left(\overbrace{\begin{matrix}p\\n-p\\m-p\end{matrix}}^{r}\Big|a,b,c,+\tfrac{1}{2}p-\overbrace{\begin{matrix}p\\n-p\\m-p\end{matrix}}^{r}\Big|a,c+\tfrac{1}{2}p-\overbrace{\begin{matrix}p\\n-p\\m-p\end{matrix}}^{r}\Big|b,c+\tfrac{1}{2}p\right)-\frac{L_{c-\frac{1}{2}p}}{L_{c}}$$

$$\left(\overbrace{\begin{matrix}p\\n\\m\end{matrix}}^{r}\Big|a,b,c-\tfrac{1}{2}p-\overbrace{\begin{matrix}p\\n\\m\end{matrix}}^{r}\Big|a,c-\tfrac{1}{2}p-\overbrace{\begin{matrix}p\\n\\m\end{matrix}}^{r}\Big|b,c-\tfrac{1}{2}p\right).$$

When the term is not very long, especially when there are many lives concerned, it will be often preferable to calculate with the usual tables by calculating each term of the expression $\overbrace{\begin{matrix}p\\n-p\\m-p\end{matrix}}^{w}\Big|\overline{N_w-N_{w+p}}\cdot M_{w+\frac{p}{2}}$, when put into the form $\overline{N_{n-p}-N_n}\cdot M_{n-\frac{p}{2}}+\overline{N_n-N_{n+p}}\cdot M_{n+\frac{p}{2}}$ &c. And I think when many lives are concerned, this will generally be the best way, if even the term should be long; but for the sake of preventing great error in such cases, or for near approximation, the following hint may be serviceable. Suppose we wished to calculate the value of $\overbrace{\begin{matrix}1\\1\\0\end{matrix}}^{w}\Big|A_w$, that is the sum of the first 80 terms of the series whose n^{th} term is A_w; then since $\overbrace{\begin{matrix}1\\1\\80\end{matrix}}^{w}\Big|A_n=\overbrace{\begin{matrix}8\\1\\73\end{matrix}}^{w}\Big|A_w+\overbrace{\begin{matrix}8\\2\\74\end{matrix}}^{w}\Big|A_w+\overbrace{\begin{matrix}8\\3\\75\end{matrix}}^{w}\Big|A_w+\overbrace{\begin{matrix}8\\4\\76\end{matrix}}^{w}\Big|A_w\ldots.$ &c. $\overbrace{\begin{matrix}8\\8\\80\end{matrix}}^{w}\Big|A_w$, that is the sum of eight terms of a

new series, whereof the first term is equal to the 1st + 9th + 17th &c. term of the original series; the second term equal to 2nd + 10th + &c. term of the original series, &c. it will follow if our original series be a gradually, but a very slowly converging series, such that $\frac{A_x}{A_{x+1}}$ differs very little from unity; since each term of the new series will be nearly equal to each other; that if this method be used, we shall have a means of detecting any great error, as it would be evinced by a too great difference produced in different terms. And if an approximation to the value be sufficient, we may avoid great labour by taking $8 \times \left|\begin{matrix} x \\ 8 \\ 5 \\ 77 \end{matrix}\right| A_x$, or $8 \times \left|\begin{matrix} x \\ 8 \\ 6 \\ 79 \end{matrix}\right| A_x$ for the value of the sum; and if r does not differ much from unity $\left|\begin{matrix} x \\ 1 \\ 1 \\ 80 \end{matrix}\right| A_x r^x$ will be nearly

$= 8 \cdot \frac{1-r^8}{1-r} \times \left|\begin{matrix} x \\ 8 \\ 5 \\ 77 \end{matrix}\right| r^{x-4} A_x$ or to $8 \cdot \frac{1-r^8}{1-r} \cdot \left|\begin{matrix} x \\ 8 \\ 6 \\ 79 \end{matrix}\right| r^{x-5} A_x$.

Art. 5. It may also be serviceable to observe, that if M_x, M'_x, M''_x, do not contain x or y, that $\left|\begin{matrix} y \\ 0 \\ x' \\ z \end{matrix}\right| (\dot{M}''_y \cdot \left|\begin{matrix} x \\ 0 \\ x \\ y \end{matrix}\right| M_x \dot{M}_x)$ by putting $\left|\begin{matrix} x \\ 0 \\ x \\ y \end{matrix}\right| M'_x \dot{M}_x = N_y$ will become $\left|\begin{matrix} y \\ 0 \\ x' \\ z \end{matrix}\right| \dot{M}''_y N_y = M''_x N''_x -$

$M''_{x'} N_{x'} - \left|\begin{matrix} y \\ 0 \\ x' \\ z \end{matrix}\right| M_y \dot{N}_y = M''_x N_x - M''_{x'} N'_{x'} - \left|\begin{matrix} y \\ 0 \\ x' \\ z \end{matrix}\right| M''_y M'_y \dot{M}_y =$

$M''_z \times \left|\begin{matrix} y \\ 0 \\ x \\ z \end{matrix}\right| M'_y \dot{M}_y - M''_{x'} \times \left|\begin{matrix} y \\ 0 \\ x \\ x' \end{matrix}\right| M'_y \dot{M}_y - \left|\begin{matrix} y \\ 0 \\ x \\ x' \end{matrix}\right| M''_y M'_y \dot{M}_y$; because

when M_v, M'_v do not contain either x or y, $\left|\begin{smallmatrix} z \\ o \\ n \\ y \end{smallmatrix}\right| M'_x \dot{M}_x = \left|\begin{smallmatrix} y \\ o \\ n \\ y \end{smallmatrix}\right| M'_y \dot{M}_y$ and therefore $\dot{N}_y = M'_y \dot{M}_y$. This form is put down for the purpose of reducing double fluents at once, such as occur in Section 4. In a similar manner may the immediate reduction of analogous triple fluents be shown; and I may remark, that in the double fluents of Section 4, the case of the question may not always require them both to commence with the same value of x. The application of the symbol $\left|\begin{smallmatrix} r \\ o \\ n \\ m \end{smallmatrix}\right|$ to all cases of definite and indefinite fluents, and of simple, double &c. fluents, might be entered on perhaps with advantage to other branches of the mathematics; but this is not my present object.

Art. 6. If in the room of M_x of Art. 4, of this Scholium, we put $r^x M_x$, M_x still being put to represent the chance that the said certain circumstance shall exist in the time x, we shall have the present value of one pound to be received immediately on the failure of the second circumstance, provided it takes place during the existence of the first circumstance, and between the times $n-p$ and m, merely by making that substitution in the expression $\left|\begin{smallmatrix} v \\ p \\ n-p \\ m-p \end{smallmatrix}\right| (\overline{N_v - N_{v+p}} \times M_{v+1p})$ by which means it will become $\left|\begin{smallmatrix} v \\ p \\ n-p \\ m-p \end{smallmatrix}\right| (\overline{N_v - N_{v+p}} \, r^{v+1p} \times M_{v+1p})$ or its equal r^{-1p}. Q; Q being put for the value of the contingency as in Article 4 of this Scholium; namely, when the payment is to be made at the first of the equal periods $n, n+p$,

&c. from the present time after the failure, provided it takes place between the intervals $n-p$ and m. And $\overset{v}{\underset{m-p}{\left[\frac{p}{n}\right]}}\left(\overline{N_v - N_{v+p}} \cdot r^{+\frac{1}{2}p} \cdot M_{v+\frac{1}{2}p}\right)$ or its equal $r^{-\frac{p}{2}} \cdot Q - \overline{N_{n-p} - N_n} \cdot r^n \cdot M_{n-\frac{1}{2}p}$ is the value if it is to be paid immediately after the failure, provided it takes place between the intervals n and m. It is necessary to add, that the method pointed out in Art. 4 of this Scholium, for solving the problems of Section 4, will generally produce results which do not agree to absolute mathematical equality, with the results of that Section, except the interval p be infinitely small; but they will agree with each other as far as the first power of p is concerned; which when p is taken, the smallest interval of the tables will be as near the truth as any method should be considered to reach, as long as the real function of life is not known; except indeed there be sufficient regularity in the tables to induce the belief that we may approach nearer by interpolation, as hinted in Art. 4, Section 3; but if the interval p be not greater than one year, this will give, I think, sufficient accuracy for any useful purpose, except perhaps in very rare cases, and in which our tables (from more minute observation), should, I imagine, be divided into less periods than yearly interval, and then the same method would still apply by taking p smaller. The same observation will apply if a comparison is made with what is done in the present Article 6 of this Scholium, with the other articles of the Scholium; for instance, with Article 3.

As an annuity secured by land, only differs from common annuities, in as much as in case of death of the lives on which the annuity is determined, during the portion of a year,

that that portion of the annuity is payable to the assignees of those persons; its value will be equal to $\left|\begin{matrix} r \\ 1 \\ n \\ m \end{matrix}\right| a, b, c, \&c. + \left|\begin{matrix} w \\ 1 \\ n-1 \\ m-1 \end{matrix}\right| \left|\begin{matrix} t \\ 0 \\ 1 \end{matrix}\right| r^{w+t} \cdot t \cdot \times \frac{-L_{w+1:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$, but if $L_{w+t:a,b,c,\&c.}$ be considered sufficiently approximated by the expression $\frac{L_{w:a,b,c,\&c.}}{L_{a,b,c,\&c.}} - \frac{L_{w:a,b,c,\&c.} - L_{w+1:a,b,c,\&c.}}{L_{a,b,c,\&c.}}$; and as a sufficient approximation for r^{w+t} we write r^{w+1}, the expression will become $\left|\begin{matrix} w \\ 1 \\ n \\ m \end{matrix}\right| a, b, c, \&c. + \left|\begin{matrix} w \\ 1 \\ n-1 \\ m-1 \end{matrix}\right| \cdot \frac{r}{2}^{w+1} \cdot \frac{L_{w:a,b,c,} - L_{w+1:a,b,c,\&c.}}{L_{a,b,c}} =$ $\left|\begin{matrix} r \\ 1 \\ n \\ m \end{matrix}\right| a, b, c, \&c. + \frac{1}{2} \cdot \left|\begin{matrix} r \\ 1 \\ n \\ m \end{matrix}\right| a, b, c, \&c.$ and will agree with Mr. BAILY'S observations on page 344 of his Doctrine of Life Annuities, as far as it goes. Note, we might with a similar proximity have omitted the t in the exponent of r; and as a nearer approximation have written $r^{w+\frac{1}{2}}$ for r^{w+1} (not deeming it necessary to go nearer), and the expression will be $\left|\begin{matrix} r \\ 1 \\ n \\ m \end{matrix}\right| a, b, c, \&c. + \frac{r^{\frac{1}{2}}}{2} \cdot \times \left|\begin{matrix} r \\ 1 \\ n \\ m \end{matrix}\right| a, b, c, \&c.$. I might make some farther observations on the comparison of the different methods pointed out, with respect to their proximity, but I fear that the length of this Paper has already caused me to occupy too large a portion of the present volume.

XVIII. *On the measurement of Snowdon, by the Thermometrical Barometer.* By the Rev. F. J. H. Wollaston, *B.D. F.R.S.*

Read June 29, 1820.

The Royal Society did me the honour to notice in their Transactions, 1817, p. 183, the description of a Thermometrical Barometer, by which it was conceived that accessible heights might with convenience be measured; and may therefore not be uninterested by the account of an actual measurement made with it. Having occasion last summer to visit Carnarvon, which would afford an opportunity of trying the instrument on the known height of Snowdon, and being aware that in 3550 feet the variations of the boiling temperature were not to be considered uniform, as they might in small elevations, on which alone I had before tried the experiment, I wished to provide myself previously with a table for making the necessary corrections; and from Dr. Ure's paper, Philosophical Transactions, 1818, p. 338, was supplied with data for the calculation. The law, which he discovers by approximation and lays down, is this: that, the elastic force of the air, or length of the column of mercury in the barometer being supposed 30 inches when water boils at 212° of Fahrenheit, $\frac{30}{1,23}$ will be the length of the column at 202°; $\frac{30}{1,23 \times 1,24}$ the length at 192°; and so on progressively, adding another increased divisor for every 10° of thermometrical temperature.

For my purpose it was necessary to calculate the variations at smaller intervals than ten degrees, and particularly to obtain those between 212° and 202°, by getting a series of

divisors for each degree, instead of the simple divisor of 1,23 for the whole. By taking the tenth of the logarithm of 1,23, the uniform divisor appears to be 1,021; but to make the successive divisors increase at the lower temperatures, as Dr. URE does, suppose them to be taken thus;

1,02059
1,02068
1,02077
1,02086
1,02095
1,02105
1,02114
1,02123
1,02132
1,02141
10,21000

The mean of which is 1.021.

The logarithms of these divisors, if their differences be equalized by a small change in the last figure, will stand thus:

88501
88892
89282
89673
90063
90454
90844
91234
91625
92105

the sum of these logarithms being 0,902583, the logarithm of 1,23 nearly.

By the use of these logarithms, the series of barometrical heights corresponding with each degree of Fahrenheit, calculated from 30 inches at 212°, downward to 202°, and carried upward to 214°, will be found in the following Table I. in the fifth column of which the difference of the logarithms of the barometric column, which corresponds by a known law with the number of fathoms of elevation, is multiplied by 6, to give the feet of elevation which produces the successive depression of the boiling point one degree of Fahrenheit; and the 6th column gives the total elevation, reckoning from the station where water boils at 212°, to any other station where the boiling temperature is at any degree between 202° and 214°. For the differences between each degree, the elevations may be taken with sufficient accuracy by simple proportion.

Table I.

1	2	3	4	5	6
Heat of boiling water.	Correspondent height of barometer.	Logarithm of height of barometer.	Difference of the Logarithms.	Difference of Logarithm multiplied by six equal feet.	Total feet from 212 degrees.
214	31,2395	4947044	87720	526,320	1054,986
213	30,6149	4859324	88111	528,666	528,666
212	30,0000	4771213	88501	531,006	0
211	29,3948	4682712	88892	533,352	531,006
210	28,7993	4593820	89282	535,692	1064,358
209	28,2133	4504538	89673	538,038	1600,050
208	27,6367	4414865	90063	540,378	2138,088
207	27,0695	4324802	90454	542,724	2678,466
206	26,5115	4234348	90844	545,064	3221,190
205	25,9627	4143504	91234	547,404	3766,254
204	25,4230	4052270	91625	549,750	4313,658
203	24,8923	3960645	92015	552,090	4863,408
202	24,3704	3868630			5415,498

In the application of this table to use, it must be adapted to the scale of the particular thermometrical barometer employed. In my former paper, I observed that a change of 1° Fahrenheit appeared to be produced by 0,589 of the common barometer. This was deduced from the comparison of my long thermometer of 3,98 inches to every degree with a common barometer. But having subsequently compared the same thermometer with a mountain barometer by Troughton, where I could ascertain the adjustment for the height of the mercury in the basin, I found that at a mean of 29,5 inches, 0,603 of barometer corrected was equal to 1° of Fahrenheit. This conclusion agrees very closely with the table deduced from Dr. Ure's observations, in which between 211° and 212°, the difference of the mercurial column is 0,605 nearly at the mean height of 29,7, and would be rather less at 29,5. On the scale of the instrument which I have now in use, the half inch is divided into ten parts, and by the Vernier into a hundred; the inch, therefore, into two hundred; and I find by observation, that 1,000 of the corrected barometer equals 372 parts on the scale of the thermometrical barometer, or 1,86 inch; consequently, 0,605 barometer or 1° Fahrenheit, = 225 parts on the scale, or $1\frac{1}{8}$ inch, which is a sensibility entirely sufficient. And those 225 parts being supposed, according to Table I, = 531 feet between 211° and 212°, 100 parts will equal 236 feet at that part of the scale. Between 202° and 203°, 225 parts = 552 feet, and, consequently, 100 parts = 246 feet nearly; and so of every other point; and the following table of heights, corresponding with the scale of my instrument, will be found in the nearest whole numbers.

TABLE II. *For converting observed differences on the Scale of the particular Thermometrical Barometer into feet of elevation.*

Fahrenheit.	Parts on the Scale of the Thermometrical Barometer.	Height in feet.	Correspondent point of Barometer nearly.
	300	702	30,8
213	225	528	,6
	200	469	,54
	100	235	,27
212	0	0	30,0
	100	236	29,73
	200	472	,46
211	225	531	,4
	300	709	29,2
	400	946	28,93
210	450	1064	,8
	500	1184	,65
	600	1422	,4
209	675	1600	,2
	700	1660	28,1
	800	1899	27,85
208	900	2138	
	1000	2378	
	1100	2618	
207	1125	2678	
	1200	2859	
	1300	3100	
206	1350	3221	
	1400	3341	
	1500	3583	
205	1575	3766	
	1600	3826	
	1700	4069	
204	1800	4313	
	1900	4556	
	2000	4800	
203	2025	4863	
	2100	5045	
	2200	5290	
202	2250	5415	24,37

A simple proportion applies this Table to the use of any other thermometrical barometer of greater or less sensibility.

As the instrument I was about to employ had a scale of only four inches, or 800 parts, and could therefore scarcely

measure at its utmost limits 1900 feet, it was necessary, on a height of 3550 feet, to divide the whole measurement into two, or, for greater security, into three lengths, and it became therefore a fair trial of the practical use of the instrument in every respect.

On the 24th of August, having occasion to ride from Carnarvon to Gregory's New Inn, near Llanberis Lake, at the foot of Snowdon, for the purpose of securing accommodations for my party, I took the instrument in my pocket, having previously boiled it on the ground floor of the Vicarage house at Carnarvon, where it stood at 517,5, thermometer 66°, barometer 30,0. In the parlour at Gregory's it stood at 401, thermometer 66°, barometer not changed during my absence; difference at the two stations 116,5.

100 : 116.5 :: 236 : 275 feet, the approximate height:

add the correction 0,089 } 24.5
× 275 from General } 299.5 feet, the corrected height
Roy's table following }

of Gregory's above the Vicarage.

The descent from the Vicarage to the north end of Carnarvon quay, was taken by levelling, and found 11,25 feet.

August 27. The instrument had been set at Gregory's at 768, before the party began to ascend the hill; but when we came to the place where the guide supposed we had ascended half way, it stood at about 300, showing that we had not gone far enough to take the whole in two lengths of the scale; and we therefore proceeded farther, to a point opposite a pass in the ridge of Snowdon, called Bwlch Cymbrwnog, by which the hill is ascended from Nant. In carrying the instrument incautiously from the former point while

cooling, the mercury was drawn into the tube from the cap at the top, and the previous measure from Gregory's was therefore lost. I mention this, to show how the measure was afterwards recovered on descending.

At this point which I call H, the half height, the thermometrical barometer was set at 792, in the manner directed in my former paper; thermometer 62°. When boiled again on the summit it stood at 86, thermometer 66°. On descending again to H, it boiled at 785, thermometer 63°. From this point, my measurement to Gregory's downward, was to be made for recovering the accidental loss in the ascent; and for that purpose an operation was to be performed on the instrument, by no means so easy as that for taking a succeeding stage upward; for the mercury must in this case be expanded out of the tube into the cap over the flame of the lamp, until on boiling, it stands as near as may be requisite to the bottom of the scale. This was done at H, and the water boiled at 146, thermometer 63°. On carrying it down to the Inn it stood at 695, thermometer 65°. The barometer observed at Carnarvon about the time of boiling at H, on ascending, was at 29,91; and at the time of boiling there the second time, it stood at 29,88, where I found it on my return to Carnarvon.

Between Gregory's and H, the difference $695 - 146 = 549$, mean thermometer 64°, barometer 29,9. Between H and the summit, the difference (from the mean of the two observations at H $\frac{792+785}{2} =$) $788{,}5 - 86 = 702{,}5$, mean thermometer 64°. The mean thermometer being the same in both lengths, they may be calculated together, the total being $549 + 702{,}5 = 1251{,}5$, thermometer 64°. The barometer

being at 29,9, I begin from the corresponding point on Table II, and take out

1250 parts between 50 and 1300 = 1300 — 118 =	2982	
1,5 - - - - - =	3,5	
1251,5 parts, giving the approximate height -	2985,5	feet.
to this add the correction from Table III, 0,0837 × 2985,5 =	250,0	
the corrected height from Gregory's to the summit	3235,5	feet.
from Vicarage to Gregory's - - -	299,5	
from Quay to Vicarage - - -	11,25	
Total from north end of Quay to summit -	3546,25	feet.

General Roy's measurement trigonometrically makes it 3555,4 feet, and barometrically 3548,9 feet.

During the same visit to Carnarvon, I took the opportunity of trying the instrument on Moel Elio, which stands between that place and Snowdon, and has also been measured by General Roy. On September 6, at the Vicarage, the thermometrical barometer stood at 737, thermometer 59°, barometer 29,8. In the blacksmith's shop at Waen Fawr, at the foot of Moel Elio, water boiled at 550, thermometer 57°. The instrument was here set to 767, and carried to the summit, where by the pile of stones it stood at 25, thermometer 52°.

From Vicarage to Waen Fawr, the difference 737 — 550 = 187, mean therm. 58°.		
187 parts - - - =	441	feet.
Add correction 0,0669 × 441 - - =	29,5	
Corrected height from Vicarage to Waen Fawr -	470,5	feet.
From Waen Fawr to the top, the difference 767 — 25 = 742, mean therm. 55°.		
742 parts taken from 258 to 1000 - - - =	1766	
Add correction 0,0583 × 1766 - - - =	102,8	
Corrected height from Waen Fawr to the top - - -	1868,8	feet.
From Vicarage to Waen Fawr - - -	470,5	
From Quay to Vicarage - - - -	11,25	
Total from north end of Quay to top of Moel Elio - -	2350,55	feet.

General Roy's measurement trigonometrically makes it 2871 feet; barometrically 2891,8 feet. The three measurements in this instance, do not agree so well as at Snowdon; whether this arises in any degree from the different forms of the two mountains, rendering the point of observation less definite in the one case, I will not pretend to say; Snowdon terminates in a point, Moel Elio has a large bare summit.

To save the trouble of reference to General Roy's Paper, Philosophical Transactions, 1777, p. 771, I give here from that Paper, a part of the Table for correction on account of the expansion of the column of air between two stations at different temperatures, in thousandth parts of an observed height.

Table III.

	28,5	difference.	29	difference.	29,5	difference.	30	difference.	30,5	difference.
12°	44,7		45,6		46,6		47,5		48,4	
		2,19		2,24		2,28		2,33		2,37
22	22,8		23,3		23,7		24,2		24,7	
	—	2,28		2,33		2,38		2,42		2,47
32	Subtract above.					Add below this line.				
	+	2,37		2,42		2,47		2,52		2,57
42	23,7		24,2		24,7		25,2		25,7	
		2,46		2,51		2,56		2,61		2,66
52	48,3		49,3		50,3		51,3		52,3	
		2,55		2,60		2,66		2,71		2,76
62	73,8		75,4		76,9		78,4		79,9	
		2,51		2,56		2,61		2,66		2,71
72	98,9		100,9		103,0		105,0		107,1	
		2,46		2,51		2,56		2,61		2,66
82	123,5		126,1		128,6		131,2		133,7	

The instrument with which these experiments were made, had been improved from the original construction as described in the Philosophical Transactions, and I shall mention the particulars of difference. The thermometer itself is straight, and carried up the middle of the scale. The index moves by hand on a square rod on one side of the glass tube,

with an adjustment by a screw at the top. The vernier is applied to the edge of the scale. I recommend that in making these thermometers, the bulb be blown on a piece of tube of $\frac{1}{4}$ inch bore, or nearly, so that the mercury expanded before boiling may be wholly contained in that tube without requiring an upper bulb; for if that bulb be made of a size to allow the mercury to separate in it, a globule may lodge in the upper part of it near the fine thread, and be attended with much inconvenience.

To protect the lamp from wind more effectually than was done by the small tent-stand formerly described, I have made the outside case of thin copper, hard soldered, so as to serve as a lanthorn to contain the lamp burning at bottom; while the boiler, which is made of a drawn tube, with the thermometer, slips down from above, and is also protected from the cold air during the experiment. The inverted boiler screws as before, over the scale of the thermometer, and packs in the centre of the case for carriage, the bulb of the thermometer going downwards into the chimney of the lamp; round the chimney in the lower part of the case, is space sufficient for stowing some matches of the oxymuriate of potash, a bottle of sulphuric acid, a wax candle, a tin bottle of water, a pair of scissors for trimming the lamp, a turnscrew and thermometer. In the upper part is also room for some tow or rag for cleaning, &c.; and the whole, when packed for use, weighs two pounds. Still farther to be guarded against wind, if necessary, I carried, as a walking-stick, a rod cut into three, and jointed at top, which belongs to a theodolite as its stand; and had in my pocket a conical bag of thin cotton, which would cover the whole as a tent,

and might be pegged down to the ground if occasion required. This precaution, though it had been needless on Snowdon, was of use on Moel Elio, where I had a very high wind. The tent has of course an opening on one side, where the instrument, which hangs from a hook in the centre, is accessible.

S. Weald,
June, 1820.

XIX. *On Sounds inaudible by certain ears.* By William Hyde Wollaston, *M. D. P. R. S.*

Read June 29, 1820.

It is not my intention to occupy the time of this Society, with the consideration of that mere general dullness to the impression of all kinds of sound which constitutes ordinary deafness, but to request its attention to certain peculiarities that I have observed with respect to partial insensibility in different states of the ear, and in different individuals; for I have found that an ear, which would be considered as perfect with regard to the generality of sounds, may, at the same time, be completely insensible to such as are at one or the other extremity of the scale of musical notes, the hearing or not hearing of which seems to depend wholly on the pitch or frequency of vibration constituting the note, and not upon the intensity or loudness of the noise.

Indeed, although persons labouring under common deafness have an imperfect perception of all sounds, the degree of indistinctness of different sounds is commonly not the same; for it will be found upon examination, that they usually hear sharp sounds much better than low ones; they distinguish the voices of women and children better than the deeper tones in which men commonly speak; and it may be remarked, that the generality of persons accustomed to speak to those who are deaf, seem practically aware of this differ-

ence, and, even without reflecting upon the motives which guide them, acquire a habit of speaking to deaf persons in a shriller tone of voice, as a method by which they succeed in making them hear more effectually than by merely speaking louder.

In elucidation of this state of hearing, which casually occurs as a malady, I have observed, that other ears may for a time be reduced to the same condition of insensibility to low sounds. I was originally led to this observation, in endeavouring to investigate the cause of deafness in a friend, by trial of different modes of closing, or otherwise lessening the sensibility of my own ears. I remarked that, when the mouth and nose are shut, the tympanum may be so exhausted by forcible attempt to take breath by expansion of the chest, that the pressure of the external air is strongly felt upon the membrana tympani, and that, in this state of tension from external pressure, the ear becomes insensible to grave tones, without losing in any degree the perception of sharper sounds.

The state to which the ear is thus reduced by exhaustion, may even be preserved for a certain time without the continued effort of inspiration, and without even stopping the breath, since by sudden cessation of the effort, the internal passage to the ear becomes closed by the flexibility of the Eustachian tube, which acts as a valve, and prevents the return of air into the tympanum. As the defect thus occasioned is voluntary, so also is the remedy; for the unpleasant sensation of pressure on the drum, and the partial deafness which accompanies it, may at any instant be removed by the act of swallowing, which opens the tube, and by allowing

the air to enter, restores the equilibrium of pressure necessary to the due performance of the functions of the ear.

In my endeavours to ascertain the extent to which this kind of deafness may be carried, some doubt has arisen, from the difficulty of finding sounds sufficiently pure for the purpose. The sound of stringed instruments are in this respect defective; for unless the notes produced are free from any intermixture of their sharper chords, some degree of deception is very liable to occur in the estimate of the lowest note really heard. I can, nevertheless, with considerable confidence, say, that my own ears may be rendered insensible to all sounds below F marked by the base cliff. But as I have been in the habit of making the experiment frequently, it is probable that other persons who may be inclined to repeat it, will not with equal facility effect so high a degree of exhaustion as I have done. To a moderate extent the experiment is not difficult, and well worth making. The effect is singularly striking, and may aptly be compared to the mechanical separation of larger and smaller bodies by a sieve. If I strike the table before me with the end of my finger, the whole board sounds with a deep dull note. If I strike it with my nail, there is also at the same time a sharp sound produced by quicker vibrations of parts around the point of contact. When the ear is exhausted it hears only the latter sound, without perceiving in any degree the deeper note of the whole table. In the same manner, in listening to the sound of a carriage, the deeper rumbling noise of the body is no longer heard by an exhausted ear; but the rattle of a chain or loose screw remains at least as audible as before exhaustion.

Although I cannot propose such an experiment as a means of improving the effect of good music, yet, as a source of amusement even from a defective performance, I have occasionally tried it at a concert with singular effect; since none of the sharper sounds are lost, but by the suppression of a great mass of louder sounds, the shriller ones are so much the more distinctly perceived, even to the rattling of the keys of a bad instrument, or scraping of catgut unskilfully touched.

Those who attempt exhaustion of the ear for the first time, rarely have any difficulty in making themselves sensible of external pressure on the tympanum; but it is not easy at first to relax the effort of inspiration with sufficient suddenness to close the Eustachian tube, and thus maintain the exhaustion: neither is it very easy to refrain long together from swallowing the saliva, which instantly puts an end to the experiment.

I may here remark, that this state of excessive tension of the tympanum is sometimes produced by sudden increase of external pressure, as well as by decrease of that within, as is often felt in the diving-bell as soon as it touches the water; the pressure of which upon the included air closes the Eustachian tube, and, in proportion to the descent, occasions a degree of tension on the tympanum, that becomes distressing to persons who have not learned to obviate this inconvenience. Those who are accustomed to descend, probably acquire the art of opening the Eustachian tube by swallowing, or incipient yawning, as soon as the diving-bell touches the water.

It seems highly probable that, in the state of artificial

tension thus produced, a corresponding deafness to low tones is occasioned, but, as I never have been in that situation, I have not had an opportunity of ascertaining this point by direct experiment.

In the natural healthy state of the human ear, there does not seem to be any strict limit to our power of discerning low sounds. In listening to those pulsatory vibrations of the air of which sound consists, if they become less and less frequent, we may doubt at what point tones suited to produce any musical effect terminate; yet all persons but those whose organs are palpably defective continue sensible of vibratory motion, until it becomes a mere tremor, which may be felt and even almost counted.

On the contrary, if we turn our attention to the opposite extremity of the scale of audible sounds, and with a series of pipes exceeding each other in sharpness, if we examine the effects of them successively upon the ears of any considerable number of persons, we shall find (even within the range of those tones which are produced for their musical effects) a very distinct and striking difference between the powers of different individuals, whose organs of hearing are in other respects perfect, and shall have reason to infer, that human hearing in general is more confined than has been supposed with regard to its perception of very acute sounds, and has probably, in every instance, some definite limit, at no great distance beyond the sounds ordinarily heard.

It is now some years since I first had occasion to notice this species of partial deafness, which I at that time supposed to be peculiar to the individual in whom I observed it. While I was endeavouring to estimate the pitch of certain sharp

sounds, I remarked in one of my friends a total insensibility to the sound of a small organ pipe, which, in respect to acuteness, was far within the limits of my own hearing, as well as of others of our acquaintance. By subsequent examination, we found that his sense of hearing terminated at a note four octaves above the middle E of the piano-forte. This note he seemed to hear rather imperfectly, but he could not hear the F next above it, although his hearing is in other respects as perfect, and his perception of musical pitch as correct as that of any ordinary ears.

The casual observation of this peculiarity in the organ of hearing, soon brought to my recollection a similar incapacity in a near relation of my own, whom I very well remember to have said, when I was a boy, that she never could hear the chirping that commonly occurs in hedges during a summer's evening, which I believe to be that of the gryllus campestris.

I have reason to think that a sister of the person last alluded to had the same peculiarity of hearing, although neither of them were in any degree deaf to common sounds.

The next case which came to my knowledge was in some degree more remarkable, in as much as the deafness in all probability extended a note or two lower than in the first instance. This information is derived from two ladies of my acquaintance, who agree that their father could never hear the chirping of the common house sparrow. This is the lowest limit to acute hearing that I have met with, and I believe it to be extremely rare. Deafness even to the chirping of the house cricket, which is several notes higher, is not common. Inability to hear the piercing squeak of the bat

seems not very rare, as I have met with several instances of persons not aware of such a sound. The chirping, which I suppose to be that of the gryllus campestris, appears to be rather higher than that of the bat, and accordingly will approach the limit of a greater number of ears; for, as far as I am yet able to estimate, human hearing in general extends but a few notes above this pitch. I cannot, however, measure these sounds with precision; for it is difficult to make a pipe to sound such notes, and still more difficult to appreciate the degree of their acuteness.

The chirping of the sparrow will vary somewhat in its pitch, but seems to be about four octaves above E in the middle of the piano-forte.

The note of the bat may be stated at a full octave higher than the sparrow, and I believe that some insects may reach as far as one octave more; for there are sounds decidedly higher than that of a small pipe one-fourth of an inch in length, which cannot be far from six octaves above the middle E. But since this pipe is at the limit of my own hearing, I cannot judge how much the note to which I allude might exceed it in acuteness, as my knowledge of the existence of this sound is derived wholly from some young friends who were present, and heard a chirping, when I was not aware of any sound. I suppose it to have been the cry of some species of gryllus, and I imagine it to differ from the gryllus campestris, because I have often heard the cry of that insect perfectly.

From the numerous instances in which I have now witnessed the limit to acuteness of hearing, and from the distinct succession of steps that I might enumerate in the

hearing of different friends, as the result of various trials that I have made among them, I am inclined to think, that at the limit of hearing, the interval of a single note between two sounds, may be sufficient to render the higher note inaudible, although the lower note is heard distinctly.

The suddenness of the transition from perfect hearing to total want of perception, occasions a degree of surprize, which renders an experiment on this subject with a series of small pipes among several persons rather amusing. It is curious to observe the change of feeling manifested by various individuals of the party, in succession, as the sounds approach and pass the limits of their hearing. Those who enjoy a temporary triumph, are often compelled, in their turn, to acknowledge to how short a distance their little superiority extends.

Though it has not yet occurred to me to observe a limit to the hearing of sharp sound in any person under 20 years of age, I am persuaded, by the account that I have received from others, that the youngest ears are liable to the same kind of insensibility. I have conversed with more than one person who never heard the cricket or the bat, and it appears far more likely that such sounds were always beyond their powers of perception, than that they never had been uttered in their presence.

The range of human hearing comprised between the lowest notes of the organ and the highest known cry of insects, includes more than nine octaves, the whole of which are distinctly perceptible by most ears, although the vibrations of a note at the higher extreme are six or seven hun-

dred fold more frequent than those which constitute the gravest audible sound.

Since there is nothing in the constitution of the atmosphere to prevent the existence of vibrations incomparably more frequent than any of which we are conscious, we may imagine that animals like the grylli, whose powers appear to commence nearly where ours terminate, may have the faculty of hearing still sharper sounds, which at present we do not know to exist, and that there may be other insects hearing nothing in common with us, but endued with a power of exciting, and a sense that perceives vibrations of the same nature indeed as those which constitute our ordinary sounds, but so remote, that the animals who perceive them may be said to possess another sense, agreeing with our own solely in the medium by which it is excited, and possibly wholly unaffected by those slower vibrations of which we are sensible.

I should be always most unwilling to occupy the time of this Society with idle speculations on mere possible modes of existence, and should not have called its attention to this subject, had I not observed several curious facts which I thought might prove interesting, and may serve to justify some latitude of conjecture beyond the strict evidence of our senses.

XX. *Particulars respecting the anatomy of the Dugong, intended as a Supplement to Sir* T. S. Raffles' *Account of that animal. By Sir* Everard Home, *Bart. F. R. S.*

Read June 29, 1820.

Sometime after Sir Thomas Stamford Raffles' paper on the Dugong was laid before the Society, I received from him a young female of that animal, four feet six inches long, and the viscera of a male, eight feet long, preserved in spirit, with the bones dried.

From these materials I have selected the most interesting facts that came under my observation, not adverted to in Sir Thomas Stamford Raffles' description, and now lay them before the Society, to render the account of this most extraordinary animal as complete as it is possible for me to do.

The external form of the animal was in sufficient preservation to enable Mr. Clift to give a representation of it, which is annexed, (Pl. XXV.)

Although the tusks, as well as the mode of shedding them, have been described in a former paper, the skull of the small dugong furnishes farther materials respecting the teeth of this animal. It has two incisors in the upper jaw immediately before the two milk tusks; these are more advanced in the gum than the tusks; and therefore, would appear before them. The gum covering the alveoli was very thick,

and a ligamentous substance passed down from it into each separate opening, and attached itself to the teeth they contain, to serve as gubernacula, to guide the points of the incisors and tusks in the right direction to pierce the gum.

The first, or temporary set of molares which had been shed in the other skulls, was in the small one twenty in number, there being five on each side of each jaw.

In the anterior scabrous projection of the lower jaw, were four regular sockets on each side, filled with a ligamentous substance passing into them from the gum, forming gubernacula for the incisors not yet completely formed.

The tongue, which is represented in one of the annexed Plates (Pl. XXVII.) of the natural size, has two nipple-like processes at its base, one on each side; it is only loose for half an inch at the point, which is covered with long villi, showing that the sense of taste is very delicate.

The insides of the cheeks are covered with cuticle, in which are strong projecting bristles, as in the hare and rabbit.

The œsophagus is lined with cuticle, which terminates before the entrance into the stomach, where the œsophageal glands are situated.

The stomach differs from all the stomachs I have yet seen; for although it possesses peculiarities met with in the whale tribe, the pecari, the hippopotamus, and beaver, even these very peculiarities are differently arranged, as will be seen by referring to the annexed drawings.

The cardiac portion is small, for an animal living on vegetable food, and extends farther to the left side beyond the entrance of the œsophagus than is usual; its form is more

globular than the human. On the upper or small curvature to the left of the entrance of the œsophagus, quite at the extremity, are situated the gastric glands, forming a rounded mass, as in the beaver. The orifices of these glands are small, and covered over with a membranous bag, which has only one large aperture. The glandular mass is divided into two portions. Their appearance is seen in Plate XXVII. and resembles more that of the same glands in the ardea argala, described in a former paper, than of any quadruped. The internal surface of this portion of the stomach is smooth, but not cuticular; the coats are thick near the cardia, but thin towards the pyloric portion. The communication between this and the pyloric portion, is by a round aperture three fourths of an inch in diameter, similar to what is met with between the different cavities of the stomach in the whale tribe. Immediately beyond this orifice there are two openings from the pyloric portion, one from the posterior side into a cul-de-sac six inches long, and one from the anterior only three inches in length. This portion is rather shorter than the cardiac, is thinner in its coats, has a smooth internal surface, and bends a little upon itself before it terminates in the pylorus, which is marked by a welt, or valve. The two appendages to the pyloric portion, differ from those in the hippopotamus and the pecari, in being smaller, and projecting farther, as well as in not belonging to the cardiac portion, as in these animals. All these cavities, including the appendages, were distended with fuci in a macerated state, undergoing trituration.

This complex stomach, belonging to an animal whose food is nearly the same as that of the hippopotamus, makes it

very desirable that the internal cavities of the stomach of that animal should be examined and described. This, I believe, has never yet been done; and, whenever an opportunity offers of sending the stomach home preserved in spirit, the opportunity, we trust, will not be lost, as it will prove a most acceptable service to Comparative Anatomy. Such an examination would probably put us in possession of all the peculiarities in the structure of the organs of digestion, that are met with in nature, for digesting vegetable substances, as well those that grow upon land, as those that grow at the bottom of the sea, or of rivers of fresh water.

The duodenum receives the ducts of the liver and pancreas about four inches from its origin at the pylorus The coats are strong, the internal surface is honeycombed, having longitudinal ridges, and smaller ones in a transverse direction. The jejunum has, on that side attached to the mesentery, a row of orifices of glands, not in one line, but in a regular zig-zag. These were very distinct in the small dugong, but could not be seen in the large one. Similar orifices are met with in the colon of the ornithorhyncus paradoxus, ranged in ten separate dotted lines. These orifices extend to the cæcum. The mesenteric glands are large, flat, oval, and thinly scattered.

The cæcum is shown in Plate XXVII.; it is four times the size of the ilium, conical in its shape, and thick in its coats.

The colon has small lacunæ over its whole surface.

The whole intestinal canal is fourteen times the length of the animal, of which the small make five, the large nine. There are no valvulæ conniventes in any part of the intestines.

The spleen is made up of a fine beautiful reticulated network.

The external opening of the nose is that of the whale tribe in miniature; and the os hyoides has the same form as in that tribe. The epiglottis is long, and has a ligamentous edge; it stands up in the posterior nostrils, but does not form a tube with the glottis, as in the whale tribe. The glottis is very similar to the human, as well as the thyroide, cricoide, and arytænoide cartilages. There are no sacculi laryngæi; but two ligaments pass forwards from the base of the arytænoide cartilages to have an attachment to the concave surface of the thyroide, forming a rimula glottidis, which can be made wider and narrower, and the ligamentous bands tighter or looser, by the action of the arytænoide muscles. I have dwelt more upon the cartilages of the larynx, which are so different from those of the whale tribe, as this animal is said to be capable of making a noise not unlike the cry of a young child. The trachea is only two inches long before it divides into two; the rings are circular, although not regularly separate from each other.

The lungs in the larger dugong are two feet in length, that is one-fourth the length of the animal; they are exceedingly elastic, and the cells are very small, about the same size as in the whale: those nearest the surface are twice as large as the others, so that they cannot readily empty themselves entirely. The rings of the bronchiæ are very strong; they are oval in their form, and run into one another. This circumstance is shown in Plate XXIX.

The greatest peculiarity in the structure of this animal, is that of the ventricles of the heart being completely detached

from one another. This is not met with in any other animal, and it is at first difficult to account for it, as the circulation of the blood does not differ from that of the whale tribe and quadrupeds in general.

It was natural to look to the heart of the whale for something at least analogous to it. In the whale, the right ventricle has its apex on the same line with that of the left, and the muscular fibres appear to be more nearly of the same length, than in the hearts of quadrupeds in general. This circumstance, of the muscular coats of the two ventricles of the whale's heart being more equal in power than is usual, renders it probable, that in the dugong, where the lungs have such uncommon length, it was necessary that the approach to equality between the two ventricles should be still greater; and this equality could in no way be so well effected as by giving the muscles of the right all the superior mechanical advantages which, in other animals, belong to the left, as was explained to the Society in the year 1790.

The ventricles, although similar in structure, are not of the same size or thickness; the left in the larger dugong, is five inches long, and thicker than the right, which is only four and a half.

The auricles have transverse elastic bands, passing from one side to the other, as in the whale. The orifice of the foramen ovale was completely closed, although the part where it had been, was distinctly marked. The valvulæ mitrales and tricuspides had nothing particular in their appearance; nor had the semilunar valves of the aorta and pulmonary artery.

The relative size of these two great trunks is the same as in the elephant.

The kidneys are long narrow conglobate, and have eleven mammæ on each side.

The form of the penis is represented in Plate XXX.; it has no bone in it, as in the hippopotamus and sea otter. This representation is taken from that of the dugong eight feet long.

The vagina is four inches long. The os tincæ takes on the form of a rose. The uterus is about three inches long. The horns go off at right angles, as in the engraving, (Pl. XXX.) which was taken from a drawing of the dugong four feet six inches long.

The cribriform plate of the ethmoide bone in the small skull, had three distinct foramina on each side, for the branches of the olfactory nerve.

The eye had a membrana nictitans. The cornea was prominent; the lens double convex, the coats thin, the nigrum pigmentum very black.

The sternum in the small dugong was ligamentous in the middle, where the cartilages of the ribs joined it. This peculiar structure, which appeared to be for the purpose of allowing the body to bend forward, was not met with in the large one, the whole being formed into one bone. The appearance is so remarkable, that it is shown in Plate XXXI.

The two bones in the flesh, substitutes for a pelvis, are shown in Plate XXXI.; they were situated opposite the fourth vertebra of the loins.

There is a bony canal in the anterior part of the spine, from the anus to the tail, for the great blood vessels, the spinous processes of which are only attached to the vertebræ by ligament.

There is only one bone corresponding to the phalanges of the thumb, and it is the same with respect to the little finger;

that belonging to the little finger is the broadest, so that the thumb (if the term may be used) is in the situation commonly occupied by the little finger.

EXPLANATION OF THE PLATES.

PLATE XXV.

The external appearance of a young dugong, upon a scale of two inches to a foot.

PLATE XXVI.

The stomach distended, to show the prominent part of the cardiac portion containing the gastric glands, the contraction between the cardiac and pyloric portion, and the two cæca that communicate with the pyloric portion; the thickening at the pylorus, and the termination of the ducts of the liver in the duodenum; on a scale of half an inch to one inch.

PLATE XXVII.

Consists of three figures.

Fig. 1. The gastric glands in one mass, and the œsophageal glands, with the orifices exposed; of the natural size.

Fig. 2. The tongue in situ, only loose for half an inch at the point; two nipple like processes at the root; the papillæ at the tip for the sense of taste; natural size.

Fig. 3. The cæcum; on a scale of half an inch to one inch.

PLATE XXVIII.

The heart, with the aorta and pulmonary artery; of the natural size; from the dugong, eight feet long. The great peculiarity of the ventricles being separate, is distinctly shown.

PLATE XXIX.

Consists of two figures of the natural size; from the dugong eight feet long.

Fig. 1. A portion of trachea below the bifurcation, to show the connection of the rings.

Fig. 2. A portion of the lungs of the same dugong, to show the appearance of the cells, and the internal surface of the bronchia.

PLATE XXX.

Consists of two figures.

Fig. 1. The glans penis of the natural size; from the dugong eight feet long.

Fig. 2. Vagina and uterus of the natural size; from the dugong, four feet six inches long.

PLATE XXXI.

Consists of two figures.

Fig. 1. The sternum in the young dugong, to show that the ribs are attached to a ligament between two portions of bone; but in the older, all these parts are ossified. The parts are of the natural size. This peculiarity must render the body more flexible at that age.

Fig. 2. The bones forming a substitute for the pelvis in the female dugong, four feet six inches long; of the natural size.

XXI. *On the compressibility of Water.* *By* JACOB PERKINS, *Esq.* *Communicated by the late Right Hon. Sir* JOSEPH BANKS, *Bart.* *G. C. B. P. R. S.*

Read June 29, 1820.

HAVING believed for many years that water was an elastic fluid, I was induced to make some experiments to ascertain the fact. This was done by constructing an instrument which I call a piezometer, and which is represented in Plate XXXII, Fig. 1. The cylinder, A, was three inches diameter, and eighteen inches long. The end, B, was made water tight by means of a plate which was soldered firmly to it. At the other end, C, a cap was made to screw on and off at pleasure; being also made water tight. The rod or plunger, D, which was five-sixteenths of an inch in diameter, was made to pass through a tight stuffing box, E. On the rod immediately above the stuffing box, was fixed a flexible ring, *a*. A cannon, Fig. 2, of a sufficient size to contain the piezometer, was fixed vertically in the earth, the muzzle being left about eighteen inches above ground, and the touch-hole plugged tight. At the mouth a strong cap, A, was firmly screwed on. In the centre of this cap a small forcing pump, B, was tightly screwed, the piston of which was five-eighths of an inch in diameter. There was an aperture, C, in the cap, to introduce a valve for the purpose of ascertaining the degree of pressure. One pound pressure on this valve indicated

an atmosphere. The piezometer was introduced into the cannon, and the water forced in until the cap showed signs of leakage; the valve at the same time indicating a pressure of one hundred atmospheres. The piezometer was then taken out of the cannon, and the flexible ring found to be eight inches up the rod, evidently proving the rod to have been forced into the cylinder that distance, showing also a compression of about one per cent. We have seen by repeated experiments, that to be able to produce this degree of compression, three per cent must be pumped into the gun. This fact proves, either that the gun expands, or that the water enters the pores of the cast iron; it is probable both these circumstances contribute to produce this effect.

This experiment was made in America in the year 1819, and before I had time to strengthen my apparatus for the purpose of making farther experiments, I was obliged to embark for this country. On my passage, however, I had frequent opportunities of repeating those I had already made, and of making others by a natural pressure. They were as follows. The piezometer, by the assistance of fifty-four pounds of lead attached to it, was sunk in the ocean to the depth of five hundred fathoms, which is about equal to the pressure of one hundred atmospheres. When drawn in, the gauge or ring was found removed eight inches up the rod, indicating, as in the before-mentioned experiment, a compression of one per cent. This experiment was several times repeated, and with the same result.

The next experiment was that of sinking a strong empty porter bottle to the depth of one hundred and fifty fathoms, having first tightly corked and sealed it, in the following

manner. Six coverings of cotton cloth, saturated with a composition of sealing wax and tar, were strongly fastened over the cork, by a cord wound round them, directly under the projection at the neck of the bottle. After the bottle had been suffered to remain at the depth mentioned a few minutes, it was drawn up. No water was found to have been forced into it, neither was there any visible change at the mouth.

The same bottle was again sunk, and at the increased depth of two hundred and twenty fathoms: when drawn in, it was found to contain about a gill of water; but not the slightest visible change had taken place in the sealing.

The same bottle was now sunk, for the third time, to the still greater depth of three hundred fathoms, and when drawn up, only a small part of the neck was found attached to the line. Its appearance was truly interesting. The bottle was not broken by external pressure, but evidently by the expansion of the condensed sea-water, which had found its way through the sealing. Upon examination, it was found that the cork had been compressed into half its length, making folds of about one eighth of an inch; and that the coverings, consisting of six layers of cloth and cement, had been torn up on one side before the bottle burst. The effect produced upon the cork cannot, we imagine, be accounted for but in one way, viz. that the water, divided into very minute particles, must, by the surrounding pressure of water, have been forced through the coverings, and filled the bottle; that the water thus forced in and condensed, to a great degree, expanded as the pressure was removed by drawing it towards the surface, not only so as to press the cork back into the neck, and, owing to the resistance of the coverings, to

compress it half its size, but to separate the neck from the body of the bottle.

Experiment 4. An empty porter bottle, the strongest that could be found, was stopped in the following manner. A cork with a large head was firmly driven into the neck; it was then covered with six layers of fine linen, saturated with a composition of tar and wax; over them was applied a covering of leather, and all perfectly secured by being well bound at the neck. The bottle thus prepared was sunk two hundred and seventy fathoms. When drawn in, it was found perfectly sound, and the sealing unchanged; but filled with water to within an inch of the cork. The coverings were taken off, layer after layer, but no signs of moisture were visible. Had the bottle remained down a sufficient length of time to have completely filled, it would undoubtedly have been broken by the expansion of the water upon being drawn towards the surface, as was the case in the former experiment. It is worthy of remark, that when the water from this bottle was poured into a tumbler, it effervesced like mineral water.

Experiment 5. In this experiment two strong bottles were sunk to the depth of five hundred fathoms. One of them was stopped with a ground glass stopper, and well cemented, then placed in a strong canvass bag. When the bag was drawn in, it was found that the bottle had been crushed into many thousand pieces. The other bottle was very tightly corked, but not having been left down a sufficient length of time, it came up whole, having filled to within one and a half inch. The cork had been driven in and remained so; but the

cementation was unaltered, excepting at the surface, where it had become a little concave.

Being satisfied that the piezometer as first constructed, would not show all the compression, I determined to make one differently modified. The object was to avoid the friction occasioned by the collapsing of the leather upon the rod under such great pressure. The drawing in Plate XXXII, Fig. 3, shows another modification of the piezometer, made since I have been in this country. This proves my suspicions to have been correct; since, under the same pressure, it indicated nearly double the compression shown by the former.

This instrument is constructed as follows, Fig. 3 being a section of it. It is simply a small tube, A, closed at the end, B, and water-tight. At the upper end, C, the water is allowed to enter through a small aperture, E, closed by a very sensible valve opening inwards. The tube is flattened at D, in order that it may yield to the expansion of the water when taken out of the press.

The experiment with this instrument was made at Mr. KIER'S manufactory, in the presence of many scientific gentlemen. The piezometer being perfectly filled with water (the weight of which was accurately known) was put into an hydraulic press, and subjected to a pressure of about three hundred and twenty six atmospheres. When it was taken out and weighed, there was found an increase of water amounting to three and a half per cent. This water had been previously boiled, and cooled down to a temperature of forty eight degrees, and kept at the same temperature during the experiment.

A machine calculated to avoid loss of pressure from destruction of the materials of which it is composed, will be made with all convenient speed. This machine being constructed with metallic stuffings and flexible metallic pistons, will effect a much greater pressure than the hydraulic press, the power of which is limited by the animal stuffing now used. It is probable, a pressure of from two to three thousand atmospheres may be obtained before the metallic piston is destroyed.

It is expected that this machine will be sufficiently accurate to give the exact ratio of the compressibility of water with much greater precision than has hitherto been obtained; but the results of farther experiments must be the subject of a future communication.

29, *Austin Friars,*
June 6, 1820.

XXII. *Astronomical Observations.* By Stephen Groombridge, *Esq. F. R. S.*

Read June 29, 1820.

Observations of the Solstices in the years 1818 and 1819.

Observed zenith distance of the Sun's centre on the meridian.

1818		Barometer.	Therm. within.	Therm. without.	Refraction.	1819		Barometer.	Therm. within.	Therm. without.	Refraction.
	° ′ ″				′ ″		° ′ ″				′ ″
June 13	28.14 53.08	29.79	72.5	81	0.29.77	June 9	28.33.30.54	29.49	61.5	68	0.30.54
14	28.11.38.72	29.87	68	66	0.30.10	16	28. 0.40.00	29.84	58	62	0.30.62
23	28. 0. 5.55	29.76	62	66	0.30.15	19	28. 1.20.52	30.00	62	68	0.30.38
27	28. 5.39.66	29.75	68	79	0.29.84	20	28. 0.21.51	30.11	62.5	66	0.30.45
28	28. 8. 9.04	29.69	66	73	0.29.97	21	27.59.47.37	30.04	62.5	68	0.30.37
29	28.10.55.40	30.08	67	72	0.30.37						
July 1	28.17 51.98	30.00	69.5	77	0.30.27						
Dec. 12	74.29.34.34	30.06	44	40	3.31.92	Dec. 13	74.32.57.59	29.70	36	32.5	3.33.32
14	74 37.55.16	30.15	43.5	42	3.34.10	26	74 48.56.96	29.44	39	32	3.35.50
19	74.50.26.17	30.21	38	34	3.40.54	27	74.46.54.68	29.39	39	34	3.33.78
22	74.52.23 59	30.45	42.5	33	3.43.15						
23	74.52. 3.00	30.31	38.5	31	3.42.94						
27	74.46.16.87	30.06	39	37	3.37.14						

The above observations computed by Mr. Groombridge's *Table of Refraction.*

1818	Zenith distance.	Equation.	Solstitial distance.	1819	Zenith distance.	Equation.	Solstitial distance.
	° ′ ″	′ ″	° ′ ″		° ′ ″	′ ″	° ′ ″
June 13	28.15.22.85	15.15.31	28. 0. 7.54	June 9	28.34. 1.08	33.54.65	28. 0. 6.43
14	11. 8.82	11.55.34	13.48	16	7.10.62	7. 1.93	8.69
23	0.35.70	0.24.45	11.25	19	1.50.90	1.39.50	11.40
27	6. 9.50	6. 1.15	8.35	20	0.51.96	0.41.67	10.29
28	8.39.01	8.27.31	11.70	21	0.17.74	0. 8.60	9.14
29	11.25.77	11.17.91	7.86				28. 0. 9.19
July 1	18.22.25	18.12.52	9.73			′	
			28. 0. 9.99		Nutation	+ 9.23	
		″			Parallax	— 4.11	+ 4.62
	Nutation	+ 7.40			Sun's Latitude	— 0.50	
	Parallax	— 4.11	+ 2.77				28. 0.13.81
	Sun's Latitude	— 0.52					
			28. 0.12.76	Dec. 13	74.36.30.91	19.36 30	74.56. 7.21
				26	52.32.46	3.32.75	5.21
Dec. 12	74.33. 6.26	22.57.04	74.56. 3.30	27	50.28.46	5.36.53	4.99
14	41.29.26	14.38.20	7.46				74.56. 5.80
19	54. 6.71	1.58.11	4.82			″	
22	56. 6.74	0. 0.18	6.92		Nutation	— 9.60	
23	55.45.94	0.17.56	3.50		Parallax	— 8.45	— 18.58
27	49.54.01	6.10.39	4.40		Sun's Latitude	— 0.53	
			74.56. 5.07				74.55.47.22
		″					28. 0.13.81
	Nutation	— 8.64					
	Parallax	— 8.45	— 17.58				2)46.55.35.41
	Sun's Latitude	— 0.49					
			74.55.47.49	1819	Mean Obliquity	- - - -	23.27.46.70
			28. 0.12.76	1818	- - - -	- - - -	23 27.47.36
			2)46.55.34.73		Mean obliquity at the vernal equinox, 1819.		23.27.47.03
	Mean obliquity, 1818		23.27.47.36				

Oppositions of the New Planets.

	Mean Time.	Right Ascension.	Declination.	Longitude.	Latitude.
	h ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
1818.	Vesta.		Par. + 5,3		
April 3	12.47.39	203.38.54.3	3.55.53.3 N	200.23.41.8	12.50.31.8 N
4	12.42.50	203.25.47.4	4. 2. 6.0	200. 8.52.1	12.51.23.5
12	12. 4. 9	201.36.56.4	4.46.53.1	198. 8.26.5	12.51.55.3
15	11.49.35	200.55.18.7	5. 0.54.2	197.23.37.9	12.49. 6.0
17	11.39.54	200.27.48.1	5. 9.18.5	196.54.22.4	12.46.24.1
	Pallas.		Par. 3.0 3.2		
Sept. 1	12.20.21	345.38.31.6	2.10.22.4 N	347.38.10.3	7.40.11.7 N
2	12.15.40	345.27.15.1	1.57.46.6	347.22.45.1	7.32.58.6
6	11.56.56	344.42. 4.6	1. 6.25.2	346.20.42.6	7. 3. 9.5
9	11.42.53	344. 8. 3.1	0.27. 5.2	345.33 48.0	6.40. 1.3
11	11.33.31	343.45.24.6	0. 0.29.5 N	345. 2.47.3	6.24.12.1
12	11.28.50	343.34. 9.1	0.12.50.9 S	344.46.50.3	6.16.13.0
13	11.24. 9	343.22.52.8	0.26.15.1	344.31.11.5	6. 8.10.1
1820.	Pallas.		Par. —6.1 —5.7		
Feb. 1	9.42.57	96.45. 6.6	25.32.13.7 S	99.15.54.7	48.47. 4.0 S
4	9.30.22	96.33.10.2	24.30.48.1	98.53.18.1	47.46.32.0
6	9.22. 9	96.27.45.0	23.49.10.4	98.41.59.8	47. 5.57.5
10	9. 6. 5	96.22.35.4	22.19.58.0	98.26.41.6	45.36.37.1
16	8.43. 1	96.30.28.2	20. 1.36.7	98.24.49.8	43.18. 4.7
17	8.39.16	96.33.26.7	19.37.58.7	98.26.38.8	42.54.19.0
	Ceres.		Par. +1.9 +1.7		
Feb. 1	11.49.38	128.30.18.9	31.29. 3.2 N	122.55. 5.1	12.19. 4.7 N
4	11.34.57	127.47. 5.7	31.44.49.4	122.14.33.3	12.25. 4.3
10	11. 5.54	126.24.49 8	32.11. 3.4	120.58.39.7	12.33.19.8
16	10.37.26	125.11.27.3	32.29.41.0	119 52.25.4	12.36.37.2
17	10.32.46	125. 0.23.1	32.32. 1.8	119.42.33.6	12.36.42.6

ERRATA.

Page 220, lines 11 and 20, for $L_{n:a,b,c,\&c.}$ read $L_{a,b,c.}$ Page 221, line 21, for $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b, c, \&c.$ read $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b, c, \&c.$ Page 224, lines 2 and 5, insert a comma before the second a; line 15, insert : before a''. Page 226, bottom line for $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}$ read $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}_{c}$. Page 227, line 14, for $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b, c, \&c.$ read $\overset{r}{\underset{m}{\overset{p}{\underset{n}{|}}}}a, b, c, \&c.$ Page 228, lines 1, 3 and 4, for $\overset{r}{\underset{m}{\overset{o}{\underset{n}{|}}}}a, b, c, \&c.$ read $\overset{r}{\underset{m}{\overset{o}{\underset{n}{|}}}}a, b, c, \&c.$; line 11, for $\overset{r}{\underset{m}{\overset{o}{\underset{n}{|}}}}a, b, c, \&c.$ read $\overset{r}{\underset{m}{\overset{o}{\underset{n}{|}}}}a, b, c, \&c.$ Page 240, line 8, for $r+1$, read $r+x$. Page 247, line 16, after $\frac{1}{\mu}$. L'_{x+n} insert (, line 17, before the period insert). Page 255, line 12, for $+\frac{1}{2}p$, read $-\frac{1}{2}p$; line 15, for $+\frac{1}{3}$, read $-\frac{1}{3}$. Page 290, line 6, for with, read without; line 14, for $\overset{w}{\underset{0}{|1|}}$ read $\overset{w}{\underset{80}{|1|1|}}$ Page 291, for N'' and N', read N. Page 294, line 5, insert i, before ;.

PRESENTS

RECEIVED BY THE

ROYAL SOCIETY,

From November 1819 to July 1820.

WITH THE

NAMES OF THE DONORS.

1819.	PRESENTS.	DONORS.
Nov. 4.	Philosophie Anatomique des Organes Respiratoires. Paris, 1818. 8°	Le Chev. Geoffroy St. Hilaire.
	Additional Experiments on the Arteries of warm blooded Animals. London, 1819. 8°	Dr. C. H. Parry.
	Observations made at Lauenberg with the Zenith Sector belonging to the Board of Ordnance in 1819. MS. F°	Professor Schumacker.
	Del Proteo Anguino di Laurenti. Monografia publicata da P. Configliachi e M. Rusconi. Pavia, 1819. 4°	Professor Configliachi and Dr. Rusconi.
	Flora Batava. No. 54 4°	H. M. the King of the Netherlands.
	Abhandlungen der Königlichen Akademie der Wissenchaften in Berlin aus den Jahren 1815-1817. Berlin, 1819. 4°	The Royal Academy of Sciences of Berlin.
	Mémoires de l'Académie Royale des Sciences de Turin, Tome 22, pour les Années 1813-1814. Turin, 1816. 4°	The Royal Academy of Sciences of Turin.
	Memorie della Reale Accademia delle Scienze di Torino, Tomo 23°. Torino, 1818. 4°	———
	Prospetto delle Letture della Sezione di Padova di Cesareo-Regio Instituto di Scienze Letture ed Arti nel Corso del Anno Accademico 1816-1817. Padova, 1817. F°	The Royal Cæsarian Institute of Sciences Literature and Arts at Padua.
	Prospetti de' Risultamenti ottenuti nella Clinica Medica di I. R. Università di Padova nel Corso del' Anni Scolastici 1815-1817. Padova, 1817. 2 vols. 8°	———
	Memorie Medico-Clinichi per servire d' Interpretazione ai Prospetti Clinici. Padova, 1816. 8°	———

1819.	PRESENTS.	DONORS.
Nov. 4	Jordani Ruffi Calabriensis Hippiatria. Patavii, 1818. 8°	Dr. Jerome Molin.
	Adversaria Zoologica, Auctore Gotthelf Fischer. Fasciculus primus. 4°	Dr. G. Fischer.
	Essai sur la Pellegrina, ou la Perle incomparable des Frères Zozima, par G. Fischer. Moscow, 1818. 8°	
	Mémoire sur la Construction des Instrumens à Cordes et à Archet, par Felix Savart, M. D. Paris, 1819. 8°	Mr. Felix Savart.
	Rotuli Scotiæ in Turri Londinensi et in Domo Capitulari Westmonasteriensi asservati. Vol. 2, 1819. f°	The Commissioners of Public Records.
	The Transactions of the Linnean Society of London, Vol. 12, Part 2. London, 1818. 4°	The Linnean Society.
	A Memoir on the Birds of Greenland, with Descriptions and Notes on the Species observed in the late Voyage of Discovery in Davis' Straits and Baffin's Bay, by Captain Edward Sabine, R. A. London, 1819. 4°	Captain Edward Sabine.
	Observations Introductory to a Work on English Etymology, by John Thomson, M. A. S. &c. London, 1819. 4°	John Thomson, Esq.
	An Inquiry into the Nature and Properties of the Blood, as existent in Health and Disease, by C. Turner Thackrah. London, 1819. 8°	C. Turner Thackrah, Esq.
	Lectures on the Blood and on the Anatomy, Physiology, and surgical Pathology of the vascular System of the human Body, by James Wilson, F. R. S. London, 1819. 8°	James Wilson, Esq.
	An Essay on Chemical Analysis, chiefly translated from the 4th Vol. of the last Edition of the Traité de Chimie Elémentaire of L. J. Thenard, with Additions, comprehending the latest Discoveries and Improvements in this Branch of the Science, by John George Children, F. R. S. London, 1819. 8°	John Geo. Children, Esq.
	A Treatise on the Nature and Cure of Gout and Rheumatism, including general Considerations on morbid States of the digestive Organs, some Remarks on Regimen, and practical Observations on Gravel, by Charles Scudamore, M. D. 3d Edition. London, 1819. 8°	Dr. Charles Scudamore.
	Medico-Chirurgical Transactions, Vol. 10, Part 1. London, 1819. 8°	The Medical and Chirurgical Society of London.
	Speech of Lieut. General William Thornton in the House of Commons, on Thursday, 7th May, on his Motion to Repeal the Declarations against the Belief of Transubstantiation, and asserting the worship of the Church of Rome to be Idolatrous, with Authorities and Illustrations, Deduction and Conclusion. London, 1818. 8°	Lieut. General William Thornton.

1819.	PRESENTS	DONORS.
Nov. 4.	A History of the high Operation for the Stone by Incision above the Pubis, with Observations on the Advantages attending it, and an Account of the various Methods of Lithotomy, from the earliest Periods to the present Time, by J. C. Carpue, Esq. London, 1819. 8°	J. C. Carpue, Esq.
	The Quarterly Journal of Literature Science and the Arts, No. 15. 8°	The Managers of the Royal Institution.
	Annals of Philosophy, No. 80-83. 8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 255 to 258. 8°	Mr. Alexander Tilloch.
	The Monthly Review for July, August, September, and October, and Appendix to Vol. 89. 8°	Mr. George Edward Griffiths.
	The European Magazine for July, August, September, and October. 8°	The Editor.
11.	Surgical Essays by Astley Cooper, F. R. S. &c. and Benjamin Travers, F. R. S. &c. Part 2. London, 1819. 8°	Astley Cooper and Benjamin Travers, Esq.
25.	The Statutes of the Realm, printed by Command of H. M. King George III. in pursuance of an Address of the House of Commons of Great Britain, Volumes 4, 5 and 6. 1819. F°	The Commissioners of Public Records.
	A Sketch (analytical) of the History and Cure of Contagious Fever, by Robert Jackson, M. D. London, 1819. 8°	Dr. Robert Jackson.
	Medical Topography of Upper Canada, by John Douglas, Assistant Surgeon, 8th Regiment. 8°	John Douglas, Esq.
	A Commentary on the Systems which have been advanced for explaining the Planetary Motions, by James Burney, Esq. R. N. and F. R. S. London, 1819. 8°	Captain James Burney.
	De l'Auscultation mediate, ou Traité du Diagnostic des Maladies des Poumons et du Cœur, fondée principalement sur ce nouveau Moyen d'Exploration, par R. T. H. Laennec. Paris, 1819. 8°	M. R. T. H. Laennec.
Dec. 9.	The Ordnance Survey of Great Britain, Part 1 to 7, comprising Essex, Devonshire, Cornwall, Dorsetshire, Sussex, Surry, and Wiltshire.	Major General Mudge.
	Esprit, Origine, et Progrès des Institutions des principaux Pays de l'Europe, par J. D. Meyer. Londres, 1819. 2 Vols. 8°	Chev. J. D. Meyer.
	Elements of a Plan for the Liquidation of the public Debt of the United Kingdom, by Richard Heathfield, Gent. London, 1819. 8°	Richard Heathfield, Esq.
	Annals of Philosophy. No. 84.	Dr. Thomas Thomson.
	The Philosophical Magazine. No. 259.	Mr. Alexander Tilloch.
	The Monthly Review for November.	Mr. George Edward Griffiths.
	The European Magazine for November.	The Editor.
16.	Mémoires de l'Academie Royale des Sciences de l'Institut de France, année 1817. Tome 2. Paris, 1819. 4°	The Royal Institute of France.

1819.	PRESENTS.	DONORS.
Dec. 23.	Ensaio Historico sobre a Origem e Progressos das Mathematicas em Portugal, por Francisco de Borja Garçao Stockler. Paris, 1819. 8°	D. Francis de Borja Garçao Stockler.
	Leçao XII. dos Elementos de Geometria Philosophica escritos por Francisco de Borja Stockler, a qual tem por titolo das Correlaçoes que existem entre as Operaçoes elementares da Technia Geometrica e da Technia Algebraica. Lisboa, 1819. 8°	
	Account of a Voyage of Discovery to the West Coast of Corea and the Great Loo Choo Island, with an Appendix, &c. by Captain Basil Hall, R. N. London, 1818. 4°	Captain Basil Hall, R.N.
	Voyage to Corea and the Island of Loo Choo, by Captain Basil Hall, R. N. a New Edition. London, 1820. 12°	
1820.		
Jan. 13.	Traité complette de Mécanique appliquée aux Arts, &c. Vol. 6 des Machines employées dans divers Fabrications, par M. J. A. Borgnis. Paris, 1819. 4°	M. J. A. Borgnis.
	Medico-Chirurgical Transactions published by the Medical and Chirurgical Society of London, Vol. 10, Part 2. London, 1820. 8°	The Medical and Chirurgical Society of London.
	Nine Charts, viz. of Gaspar Straits, Carimata Passage, West part of Kilo Leet, Lucepar Channel, Romania Channel, Singapore New Settlement, Samangca Bay, Coloombyan Harbour, and Survey of the entrance of Hoogley River, by James Horsburgh, Esq.	James Horsburgh, Esq.
	Mémoire sur l'Utilité des Pièces d'Anatomie artificielle chirurgicale, par J. F. Ameline. Paris, 1819. 8°	M. J. F. Ameline.
	The Quarterly Journal of Literature Science and the Arts, No. 16. 8°	The Managers of the Royal Institution.
	Annals of Philosophy, No. 85. 8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 260. 8°	Mr. Alexander Tilloch.
	The Monthly Review for December. 8°	Mr. George Edward Griffiths.
	The European Magazine for December. 8°	The Editor.
	The London Magazine, No. 1. 8°	The Editors.
	A Treatise on Nervous Diseases, by John Cooke, M. D. Vol. 1. London, 1820. 8°	Dr. John Cooke.
	A Dissertation on the Disorder of Death, or that State of the Frame under the Signs of Death called suspended Animation, &c. by the Rev. Walter Whiter. Norwich, 1819. 8°	The Rev. Walter Whiter.
20.	Esperienze ed Osservazione sul Galvanismo, Memoria del Sig. Carlo Francesco Bellingeri, M.D. 4°	Dr. Carlo Francesco Bellingeri.

1820.	PRESENTS.	DONORS.
Jan. 20.	Caroli Francisci Josephi Bellingeri Dissertatio Chemica Inauguralis quam publicè defendebat in Regio Atheneo 9 Maii, 1818. Augustae Taurinorum, 1818. 8°	Dr. Carlo Francesco Bellingeri.
	Réglement de la Société d'Instruction Medicale, par Le Chev. J. J. Leroux. Paris, 1818. 4°	M. Leroux, Doyen de la Faculté de Medecine à Paris.
	Travels in Nubia by the late John Lewis Burckhardt, published by the Association for Promoting the Discovery of the Interior parts of Africa. London, 1819. 4°	The Committee of the Association for Promoting the Discovery of the Interior Parts of Africa.
Feb. 17.	Flora Batava, No. 55. 4°	H. M. The King of the Netherlands.
	Zoognosia Tabulis Synopticis illustrata in usum Praelectionum Academiæ Imper. Med. Chirurg. Mosquensis edita. Auct. Gotthelf Fischer. Mosquiæ, 1813 et 1814. 3 vols. 4° and 8°	Dr. Gotthelf Fischer.
	Notizen über die Mineralien Sammlung S. Excellenz des Herren Drs. Alexanders von Crichton, von Joseph Frederick Wagner. Moskwa, 1818. 4°	Mr. Joseph Frederick Wagner.
	An Account of the variolid Epidemic which has lately prevailed in Edinburgh and other Parts of Scotland, with Observations on the Identity of Chicken Pox with modified Small Pox; in a Letter to Sir James M'Grigor, by John Thomson, M. D. London, 1820. 8°	Dr. John Thomson.
	Annals of Philosophy, No. 86. 8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 261. 8°	Mr. Alexander Tilloch.
	The Monthly Review for January, and Appendix to Vol. 90. 8°	Mr. George Edward Griffiths.
	The European Magazine for January. 8°	The Editor.
	The London Magazine, No. 2. 8°	The Editors.
	An Introduction to Solid Geometry, and to the Study of Crystallography, containing an Investigation of some of the Properties belonging to the Platonic Bodies independent of the Sphere, by N. J. Larkin, M. G. S. London, 1820. 8°	Mr. N. J. Larkin.
	A View of the Lead Mines of the Missouri, including some Observations on the Mineralogy, Geology, Geography, Antiquities, Soil, Climate, Population, and Productions of Missouri and Arkansaw, and other Sections of the Western Country, by Henry R. Schoolcraft. New York, 1819. 8°	Dr. David Hosac.
	A Biographical Memoir of Hugh Williamson, M. D. LL. D., by David Hosac, M. D. New York, 1820. 8°	
	Bibliotheca MS. Stowensis. A Descriptive Catalogue of the Manuscripts in the Stow Library, by the Rev. Charles O'Connor, D. D. Buckingham, 1818. 2 Vols. 4	The Marquis of Buckingham.

1820.	PRESENTS.		DONORS.
Mar. 2.	The Nautical Almanac and Astronomical Ephemeris for 1822.	8°	The Commissioners of Longitude.
	A Catalogue of the Lansdown Manuscripts in the British Museum, with Indexes of Persons, Places, and Matters, printed by command of H. M. King George III. Parts 1 and 2. 1812, 1819.	Fo	The Commissioners of Public Records.
	Annals of Philosophy, No. 87.	8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 262.	8°	Mr. Alexander Tilloch.
	The Monthly Review for February.		Mr. George Edward Griffiths.
	The European Magazine for February.		The Editor.
	The London Magazine, No. 3.		The Editors.
	Meteorological Journal kept on board the Marine Society's Ship off Deptford Creek in the years 1816, 1817, 1818, 1819. MS.		The Committee of Governors of the Marine Society.
	Transactions of the Society instituted at London for the Encouragement of Arts Manufactures and Commerce, Vol. 37. London, 1820.	8°	The Society for Encouragement of Arts, &c.
9.	Annales des Mines ou Recueil de Mémoires sur l'Exploitation des Mines et sur les Sciences qui s'y rapportent. Année 1818, Liv. 2, 3, et 4. et Année 1819, Liv. 1, 2, 3. Paris.	8°	Conseil Général des Mines de France.
	De' Contagi e de la cura di loro Effetti, Lezione Medica Practiche del Cav. Valeriano Luigi Brera, M. D. Padova, 1819. 2 Vols.	8°	Il Cav. Valeriano Luigi Brera.
	Prospetti de' Risultamente ottenuti nella Clinica Medica dell' I. R. Universita di Padova nel Anni Scolastici, 1809—1816 del Sig. V. L. Brera, M. D. Padova, 1816 e 1817. 2 Vols.	8°	———
	Prospetto della Letture della Sezione di Padova del Caesareo Reg. Instituto di Scienze Lettere ed Arti nel corso del' Anno Accademico 1816-1817. Padova, 1817.	4°	———
	Statuta della I. R. Accademia di Scienze Lettere ed Arti di Padova, e Catalogo degli Accademici. Padova, 1816.	4°	———
April 13.	Journal of the Academy of Natural Sciences of Philadelphia, Vol. 1, part 2. Philadelphia, 1818.	8°	The Academy of Natural Sciences, Philadelphia.
	A Journal of Science Literature and the Arts, No. 17.	8°	The Managers of the Royal Institution.
	Annals of Philosophy, No. 88.	8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 263.	8°	Mr. Alexander Tilloch.
	The Monthly Review for March.	8°	Mr. George Edward Griffiths.
	The European Magazine for March.	8°	The Editor.
	The London Magazine, No. 4.	8°	The Editors.
	Notice sur l'Archipel de Jean Potocki situé dans la Partie septentrionale de la Mer Jaune, par Jules Klaproth, avec une Carte. Paris, 1820.	4°	M. Jules Klaproth.

1820.	PRESENTS.	DONORS.
April 13.	General Views of the Application of Galvanism to Medical Purposes, principally in Cases of Suspended Animation, by John Aldini. London, 1819. 8°	Mr. John Aldini.
27.	Commentationes Societatis Regiæ Scientiarum Gottingensis Recentiores, Volumen 4 ad A. 1816-1818. Gottingæ, 1820. 4°	The Royal Society of Sciences of Gottingen.
	Jo. Frid. Blumenbachii decas sexta Collectionis suæ Craniorum diversarum Gentium illustrata. Gottingæ, 1820. 4°	Professor J. F. Blumenbach.
May 4.	A Dictionary of the Chinese Language, containing all the Characters which occur in the original Chinese Dictionary, in 32 Volumes, compiled in 1716, by order of H. M. Kang He, Emperor of China, by the Rev. R. Morrison, Vol. 1, part 3. Macao, 1818. 4°	The Court of Directors of the Hon. East India Company.
	Annals of Philosophy, No. 79. 8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 264. 8°	Mr. Alexander Tilloch.
	The Monthly Review for April. 8°	Mr. George Edward Griffith.
	The European Magazine for April. 8°	The Editor.
	The London Magazine, No. 5. 8°	The Editors.
11.	Transactions of the Horticultural Society, Vol. 4. Part 2. London, 1820. 4°	The Horticultural Society.
	Geological Map of England in 6 Sheets and Memoir of a Geological Map of England, to which are added an Alphabetical Index to the Hills, and a List of the Hills arranged according to Counties, by G. B. Greenough, Pres. Geol. Soc. &c. London, 1820. 4°	G. B. Greenough, Esq.
	The Modern London Catalogue of Books, with their Sizes, Prices, and Publishers. London, 1818. 8°	Mr. William Bent.
	Vindiciæ Geologicæ, or the Connection of Geology with Religion explained, in an Inaugural Lecture delivered before the University of Oxford, May 15, 1819, on the Endowment of a Readership in Geology, by H. R. H. the Prince Regent; by the Rev. W. Buckland, B. D. &c. Oxford, 1820. 4°	Rev. William Buckland.
18.	Mémoire sur la Digue de Cherbourg comparée au Breakwater ou Jetée de Plymouth, par J. M. F. Cachin. Paris, 1820. 4°	M. J. M. F. Cachin.
	Su la Falsità dell' Origine Scandinava data ai Popoli detti Barbari che distrussero l' Impero di Roma, Dissertazione Istorica di Jacopo Gråberg di Hemsö. Pisa, 1815. 8°	Sig. Jacopo Gråberg di Hemsö.
	Appellation au Parlement de la Grande Bretagne, by Hoëne Wronski. London, 1820. 12°	M. Hoëne Wronsky.
	A Journey in Carniola, Italy, and France, in the years 1817 and 1818, containing remarks relating to Language, Geography, History, An-	W. A. Cadell, Esq.

1820.	PRESENTS.	DONORS.
	tiquities, Natural History, Science, Painting, Sculpture, Architecture, Agriculture, the Mechanical Arts and Manufactures, by W. A. Cadell, Esq. with Engravings. Edinburgh, 1820. 2 Vols. 8°	
	A Circumstantial and Explanatory Account of Experiments lately made with a View of ascertaining the comparative Accuracy of the relative Times of Burning of Fuzes, &c. with an Appendix on the present state of Telegraphic Communication in this Country, by John Macdonald, Esq. London, 1819. 8°	Lieut. Col. John Macdonald.
	ΜΕΛΕΤΗ ΤΗΣ ΚΟΙΝΗΣ ΕΛΛΗΝΙΚΗΣ ΔΙΑΛΕΚΤΟΥ, or Study of the Modern Greek Language, by P. Codrika, Vol. 1. Paris, 1818. 8°	Mr. P. Codrika.
June 1.	Astronomical Observations made at the Radcliffe Observatory at Oxford, from May 1, 1819, to May 1, 1820, by and under the direction of the Rev. Abram Robertson, D. D. F. R. S. Sav. Prof. of Astron. and Radcliffian Observer. MS. F°	The Trustees under the Will of the late Dr. Radcliffe.
	Transactions of the Geological Society, established Nov. 13, 1807, Vol. 5, Part 1. London, 1819 4°	The Geological Society.
	Traité complet de Mécanique appliquée aux Arts, par M. J. A. Borgnis, Vol. 7, Des Machines qui servent à confectioner les Etoffes. Paris, 1820, 4°	M. J. A. Borgnis.
	Essays on the Combinatorial Analysis, showing its Application to some of the most useful and interesting Problems of Algebra, by Peter Nicholson London, 1818. 8°	Mr. Peter Nicholson.
	Essay on Involution and Evolution, containing a new general and accurate Method of ascertaining the numerical Value of any Functions of an unknown Quantity, by P. Nicholson. London, 1820. 8°	———
	The Rudiments of Algebra, by P. Nicholson. London, 1819. 12°	———
	Annals of Philosophy, No. 90. 8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 265. 8°	Mr. Alexander Tilloch.
	The Monthly Review for May, and Appendix to Vol. 91. 8°	Mr. George Edward Griffiths.
	The London Magazine, No. 6. 8°	The Editors.
	The European Magazine for May. 8°	The Editor.
8.	Flora Batava, No. 56. 4°	H. M. The King of the Netherlands.
	The Ordnance Survey of Great Britain, part 8.	Captain Thomas Colby.
	Report of the Lords Committees appointed to search the Journals of the House Rolls of Parliament and other Records and Documents for all Matters touching the Dignity of a Peer of the Realm, &c. May 25, 1820. F°	Lord Redesdale.

1820.	PRESENTS.	DONORS.
June 29.	The Hunterian Oration delivered before the Royal College of Surgeons in London, on Monday, February 21, 1820, by Anthony Carlisle, Esq. F. R. S. London, 1820. 4°	Anthony Carlisle, Esq.
	Lettera di Francesco Gianpietri intorno alle Monete Aragonese ultimamenti trovati nella Cupra di St. Efrem, all' Excellentissimo Cavaliere Luigi de' Medici. Naples, 1819. 4°	Sig. Francesco Gianpietri.
	Annals of Oriental Literature, Part 1. For June 1820. 8°	The Editor.
	Annals of Philosophy, No. 91. 8°	Dr. Thomas Thomson.
	The London Magazine, No. 7.	The Editors.
	On Circular Polarisation, as exhibited in the Optical Structure of the Amethyst, with Remarks on the Distribution of the Colouring Matter in that Mineral, by David Brewster, LL. D. Edinburgh, 1820. 4°	Dr. David Brewster.
July 7.	ΔΙΟΝΥΣΙΟΥ ΑΛΙΚΑΡΝΑΣΣΕΩΣ ΡΩΜΑΪΚΗΣ ΑΡΧΑΙΟΛΟΓΙΑΣ ΤΑ ΜΕΧΡΙ ΤΟΥΔΕ ΕΛΛΕΙΠΟΝΤΑ. Dionysii Halicarnassei Romanarum Antiquitatum Pars hactenus desiderata nunc denique ope Codicum Ambrosianarum ab Angelo Majo, Ambrosiani Collegii Doctore, quantum licuit restituta. Opus Francisco I. Augusto sacrum. Mediolani, 1816. 4°	H. R. H. the Archduke Maximilian.
	Eusebii Pamphili Chronicorum Canonum Libri Duo. Opus ex Haicano Codice a Doctore Johanne Zohrabo Collegii Armeniaci Venetiarum Alumno diligenter expressum et castigatum, Angelus Maius et Johannes Zohrabus nunc primum conjunctis Curis Latinitate donatum Notisque illustratum, addita Graecis Reliquiis, ediderunt. Mediolani, 1818. 4°	———
	M. Tullii Ciceronis sex Orationum Partes ante nostram Aetatem ineditæ cum antiquo interprete ante nostram item Aetatem inedito qui videtur Asconius Pedianus ad Tullianas septem Orationes. Accedunt Scholia minora vetera. Editio altera quam ad Codices Ambrosianos recensuit emendavit et auxit ac Descriptione Codicum CXLIX. Vita Ciceronis aliisque Additamentis instruxit Angelus Maius, Amb. Colleg. Doct. Mediolani, 1817. 8°	———
	Isocratis Oratio de Permutatione, cujus Pars ingens primum Græcè edita ab Andrea Mustoxido, nunc primum Latinè exhibetur ab Anonymo Interprete, qui et Notas et Appendices adjunxit. Mediolani, 1813. 8°	———
	M. Cornelii Frontonis Opera inedita, cum Epistolis item ineditis Antonini Pii, M. Aurelii, L. Veri, et Appiani, nec non Aliorum Veterum	———

1820.	PRESENTS.	DONORS.
July 7.	Fragmentis invenit et Commentario præviо Notisque illustravit Angelus Maius Bibliothecæ Ambrosianæ a Linguis Orientalibus. Cui adduntur seu edita seu cognita ejusdem Frontonis Opera. Mediolani, 1815. 2 Vols. 8°	
	Philonis Judæi de Copheni Festo et de Colendis Parentibus, cum brevi Scripto de Iona, Editore et Interprete Angelo Maio, A. C. D. Reg. Belg. Inst. Sod. ad Leopoldum Principem Etruriæ Heredem. Mediolani, 1818. 8°	H. R. H. The Archduke Maximilian.
	Virgilii Maronis Interpretes veteres Asper Cornutus, Hasterianus Longus, Nisus Probus, Scaurus Sulpicius, et Anonymus, edente notisque illustrante Angelo Maio, A. C. D. Reg. Belg. Inst. Sod. ad Leopoldum Principem Etruriæ Heredem. Mediolani, 1818. 4°	———
	ΠΟΡΦΥΡΙΟΥ ΦΙΛΟΣΟΦΟΥ ΠΡΟΣ ΜΑΡΚΕΛΛΑΝ. Porphyrii Philosophi ad Marcellam, invenit Interpretatione Notisque declaravit Angelus Maius, A. C. D. Acad. R. Monac Sod. Accedit ejusdem Porphyrii Poeticum Fragmentum. Mediolani, 1816. 4°	———
	De Philonis Judæi et Eusebii Pamphilii Scriptis ineditis Aliorumque Libris ex Armeniaca Lingua convertendis Dissertatio, cum ipsorum Operum Philonis ac præsertim Eusebii Specimibus, scribente Angelo Maio, A. C. D. ex Notitia sibi ab Armeniacorum Codicum Dominis impertita. Mediolani, 1816. 8°	———
	Q. Aurelii Symmachi, V. C. Octo Orationum ineditarum Partes, invenit Notisque declaravit Angelus Maius, Bibliothecæ Ambrosianæ a Linguis Orientalibus. Accedunt Additamenta quædam. Mediolani, 1815. 8°	———
	Itinerarium Alexandri ad Constantium Augustum, Constantini M. Filium, edente nunc primum cum Notis Angelo Maio, Amb. Coll. Doct. Mediolani, 1817. 4°	———
	ΣΙΒΥΛΛΗΣ ΛΟΓΟΣ ΙΔ. Sibyllæ Liber XIV. Editore et Interprete Angelo Maio, Amb. Coll. Doct. Additur Sextus Liber et Pars Octavi, cum multa Vocum et Versuum Varietate. Mediolani, 1817. 4°	———
	M. Accii Plauti Fragmenta inedita, item ad P. Terentium Commentationes et Picturæ ineditæ. Inventore Angelo Maio, Bib. Ambros. A. LL. Or. Mediolani, 1815. 8°	———
	ΙΣΑΙΟΥ ΛΟΓΟΣ ΠΕΡΙ ΤΟΥ ΚΛΕΩΝΥΜΟΥ ΚΛΗΡΟΥ. Isæi Oratio de Hereditate Cleonymi nunc primum duplo Auctor Inventore et Interprete Angelo Maio, Bib. Amb. A. LL. OR. Mediolani, 1815. 8°	———

1820.	PRESENTS.	DONORS.
July 7.	Julii Valerii Res Gestae Alexandri Macedonis translatæ ex Aesopo Graeco, prodeunt nunc primum, edente Notisque illustrante Angelo Maio, A. C. D. Mediolani, 1817. 4°	H. R. H. The Archduke Maximilian.
	ΘΕΜΙΣΤΙΟΥ ΦΙΛΟΣΟΦΟΥ ΛΟΓΟΣ ΠΡΟΣ ΤΟΥΣ ΑΙΤΙΑΣΑΜΕΝΟΥΣ ΕΠΙ ΤΩΙ ΔΕΞΑΣΘΑΙ ΤΗΝ ΑΡΧΗΝ. Themistii Philosophi Oratio in eos a quibus ob Præfecturam susceptam fuerat vituperatus, Inventore et Interprete Angelo Maio, Bib. Amb. A. LL. OR. Mediolani, 1816. 8°	———
	Lettera di Pietro Giordani al chiarissimo Abate Giambatista Canova, sopra il Dionigi trovato dall' Abate Mai. Milano, 1817. 8°	———
	Théorie Analytique des Probabilités, par M. Le Marquis de Laplace, 3ème Edition. Paris, 1820. 4°	The Marquis de Laplace.
	A Treatise on the Anchor, shewing how the component Parts should be combined to obtain the greatest Power and most perfect Holding, with a Table of Dimensions, &c. Also some Observations on the Chain Cable, by Richard Pering, Esq. Plymouth Dock, 1819. 8°	Richard Pering, Esq.
	A Brief Inquiry into the Causes of Premature Decay in our Wooden Bulwarks, with an Examination of the Means best calculated to prolong their Duration, by Richard Pering, Esq. Plymouth Dock, 1812. 8°	———
	On the Preservation of the British Navy when in a State of Ordinary, by R. Pering, Esq. 1813. 8°	———
	A Reply to the Strictures in the Quarterly Review on Indian built Ships, to which are annexed economical Recommendations for effectually preserving the British Navy on the return of Peace, &c. By Richard Pering, Esq. Plymouth Dock, 1814. 8°	———
	A Journal of Science, Literature, and the Arts, No. 18. 8°	The Managers of the Royal Institution.
	Annals of Philosophy, No. 91. 8°	Dr. Thomas Thomson.
	The Philosophical Magazine, No. 266. 8°	Mr. Alexander Tilloch.
	The Monthly Review for June 8°	Mr. George Edward Griffiths.
	The European Magazine for June. 8°	The Editor.
	The London Magazine, No. 7. 8°	The Editors.

INDEX

TO THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1820.

A

page

Alburnum, upon the different qualities of the alburnum of spring and winter-felled oak-trees - - 156

Aneurismal tumor, a description of a deposit of crystals found in one, - - - 3

Apophyllite, of its anomalous tints, - - 76

——— the only crystal with one axis, whose tints exhibit a sensible deviation from the scale of Newton, 91

——— its tints commence at the centre of the rings and increase in regular progression outwards, - 91

Astronomical observations, - - - 330

B

Bakerian Lecture, by WILLIAM THOMAS BRANDE, Esq. Sec. R. S. - - - - 11

Barometer, thermometrical, a description of some improvements made in this instrument, - - 303

BAUER, FRANCIS, Esq. Some experiments on the fungi which constitute the colouring matter of the red snow discovered in Baffin's Bay, - - - 165

Blood, a farther investigation of its component parts, 1

———an experiment to ascertain whether the proportion of aeriform matter in the blood is liable to vary, - 6

———*coagula of*, examination of those formed in aneurismal tumors, - - - - 2

INDEX

page

BRANDE, WILLIAM THOMAS, Esq. The Bakerian Lecture. On the composition and analysis of the inflammable gaseous compounds resulting from the destructive distillation of coal and oil, with some remarks on their relative heating and illuminating powers, - 11

Breathing, the effect of an interminable contest between the elasticity of the lungs and the irritability of the diaphragm, - - - - 43

BREWSTER, DAVID, LL. D. Extracts of two letters from him, on the deviation of the tints from Newton's scale, 94

C

CARSON, JAMES, M. D. On the elasticity of the lungs, 29

Chocks, or wedge pieces, first introduced in naval architecture, about the year 1744, - - - 135

——— reason of their introduction, 135

——— the substitution of coaks or dowels for them recommended, - - - 137

Chronometers used at sea, their rates affected by the iron in the ships, - - - 196

Coal and oil, experiments on the inflammable gases afforded by their destructive distillation, 11

COLEMAN, GEORGE, Esq. His communication of some tables showing the rates of chronometers, - - 208

Corpora cavernosa, their cellular structure explained, 188

Corpus spongiosum, the particulars in which its structure differs from that of the corpora cavernosa, 190

Croonian Lecture. By Sir EVERARD HOME, Bart. 1

Crystals, of the general phenomena of those which develope tints deviating from NEWTON's scale, by exposure to polarised light, 52

——— on the causes which produce the above phenomena in crystals, 62

——— on the tints developed by those with two axes, out of the principal section, 73

——— of a secondary cause of the deviation of tints, subsisting in certain crystals, and of the anomalous tints of the apophyllite, 76

Crystallised bodies, on their action upon homogeneous light, and on the causes of the deviation from NEWTON's scale, in the tints which many of them develope on exposure to a polarised ray, - - - - - 45

INDEX.

D

page

Davy, Edmund, Esq. On some combinations of platinum, 108
Deafness, instances of a particular species of partial deafness, or insensibility of very acute sounds, - 310
Dugong, some account of that animal, - - - 174
———a description of its external appearance, 175
———dissection of it, - - - - 177
———its food, - - - - - 179
———never found on land, or in fresh water, but generally in the shallows and inlets of the sea, - 180
———its dimensions, - - - - 181
———the ventricles of the heart of this animal completely detached, - - - - - 319
———particulars respecting the anatomy of this animal, intended as a supplement to Sir T. S. Raffles' account, 315
———on the milk tusks, and organ of hearing of this animal, - - - - - 144
———a section of the milk tusk of the narwhal and of the elephant, compared with a similar section of that of the dugong, - - - - - 147
Dugong Ikan, considered by the Malays as a royal fish, 180
———the Malays distinguish two varieties, the dugong *bumban*, and the dugong *buntal*, - - 180

E

Eustachian tube, is closed by suddenly checking the effort of inspiration, - - - - - - 309
———is opened by swallowing or incipient yawning, - - - - - 309

F

Fisher, George, Esq. On the errors in longitude as determined by chronometers at sea, arising from the action of the iron in the ships upon the chronometers, - 196
Fœtus, human, a case of one found in the ovarium, of the size it usually acquires at the end of the fourth month, 101
Frames, or ribs of ships, a new principle of uniting them recommended, - - - - 134

INDEX.

G

page

Gases, inflammable, experiments on those afforded by the destructive distillation of pit coal and of oil, - 11

Gas, olefiant, coal, and oil, comparative experiments on their illuminating and heating powers, and on some general properties of radiant matters, - - - 21

GOMPERTZ, BENJAMIN, Esq. A sketch of an analysis and notation applicable to the estimation of the value of life contingencies, - - - 214

GRANVILLE, AUGUSTUS BOZZI, M. D. A case of the human fœtus found in the ovarium, of the size it usually acquires at the end of the fourth month, - - 101

GROOMBRIDGE, STEPHEN, Esq. Astronomical observations, - - - - - 330

H

Hearing, human, its range, - - - 313

HERSCHEL, J. F. W. Esq. On the action of crystallized bodies on homogeneous light, and on the causes of the deviation from NEWTON'S scale, in the tints which many of them develope on exposure to a polarised ray, - 45

HOME, Sir EVERARD, Bart. Croonian Lecture. A farther investigation of the component parts of the blood, - 1

——— On the milk tusks, and organ of hearing of the dugong, - - - - 144

——— On the mode of formation of the canal for containing the spinal marrow, and on the form of the fins (if they deserve that name) of the proteosaurus, - - - - - 159

——— Observations on the human urethra, showing its internal structure, as it appeared in the microscope of FRANCIS BAUER, Esq. - - 183

——— An account of a new mode of performing the high operation for the stone, - 209

——— Particulars respecting the anatomy of the dugong, intended as a supplement to Sir T. S RAFFLES' account, - - 315

K

KNIGHT, THOMAS ANDREW, Esq. Upon the different qualities of the alburnum of spring and winter-felled oak-trees, - - - - - 156

L

page
LEGUAT, Mr. His account of the habits of the dugong, 150
Life contingencies, a sketch of an analysis and notation applicable to the estimation of their value, 214
Light, homogeneous, on the action of crystallized bodies on it, 43
Lizard tribe, the structure of their vertebræ, 160
Longitude, on the errors in longitude as determined by chronometers at sea, arising from the action of the iron in the ships upon the chronometers, 196
Lungs, on the elasticity of them, 29
——— experiments to ascertain the extent of the power to distend them to the dimensions which they occupy in the sound system, 35
Lyme, fossil organic remains discovered in the cliffs at that place, 159

M

Malabar, 74 guns, extract from the survey made by the officers of Plymouth Yard on that ship, 142
Mesentèric glands, examination of their contents, in the case of a man who died in a fit an hour after having eaten his dinner, 7
Micrometers, on the method of cutting rock crystal for them, 126
Moel Elio, its measurement by the thermometrical barometer, 302

N

Narwhal, a section of the milk tusk of this animal compared with a similar section of that of the dugong, 147
Nitre, crystal of, mode of examining its rings, by projecting them on a large sheet of paper, stretched, while moist, on a drawing board, 80

P

PERKINS, JACOB, Esq. on the compressibility of water, 324
Planets, new, their oppositions, 331
Platinum, on some combinations of it, 108
——— on a peculiar compound of it obtained from sulphate of platinum by the agency of alcohol, 108

page

Platinum, properties of this peculiar compound of platinum, - - - - - 110
——— composition of this peculiar compound of platinum, - - - - - 111
——— observations on this peculiar compound of platinum, - - - - - - 115
Platinum, grey oxide of, observations on it, - - 121
——— properties and composition of it, 121
Platinum, sulphate of, its effects upon gelatine, - 118
——— on the efficacy of this substance as a test for gelatine, - - - - 119
Polarised rings, description of an instrument employed in experiments upon them, - - - - 96
Presents, a list of those made to the Royal Society, from November 1819 to July 1820, - - - - 333
Proteosaurus, on the mode of formation of the canal for containing the spinal marrow, and on the form of the fins (if they deserve that name) of this animal, - 159
——— the structure of its vertebræ, - - 160

R

Raffles, Sir Thomas Stamford. Some account of the dugong, - - - - - - 174
Rochon, M. Extract of a paper of his in the Journal de Physique, relative to the construction of micrometers, 130
Rock crystal, on the method of cutting it for micrometers, 126

S

Seppings, Sir Robert On a new principle of constructing ships in the mercantile navy, - - 133
Ships, on a new method of constructing them in the mercantile navy, - - - - - 133
Snow, red, some experiments on the fungi which constitute the colouring matter in that discovered in Baffin's Bay, 165
Snowdon, on the measurement of that mountain by the thermometrical barometer, - - - 295
Solstices, observations of those in the years 1818 and 1819, 330
——— observations of those in the years 1818 and 1819, computed by Mr. Groombridge's table of refraction, 330
Sounds, on those inaudible by certain ears, - - 306
Stone, an account of a new mode of performing the high operation for that disease, - - 209

page

T

Thunderer, now Talavera, report of the officers of his Majesty's yard at Woolwich to the Navy Board, establishing the superior strength of the construction of this ship, 138

U

Urethra, human, observations upon it, showing its internal structure, as it appeared in the microscope of FRANCIS BAUER, Esq. - - - - - 183

Vertebræ, the structure of those of the Proteosaurus, - 160

——— the structure of those of the lizard tribe, - 160

W

Water, on the compressibility of it, - - - 324

WOLLASTON, F. J. H., B. D. On the measurement of Snowdon, by the thermometrical barometer, - - 295

WOLLASTON, WILLIAM HYDE, M. D. On the methods of cutting rock crystal for micrometers, - - 126

——— On sounds inaudible by certain ears, - - - - - 306

From the Press of
W. BULMER & Co.
Cleveland-row, St. James's,
London.